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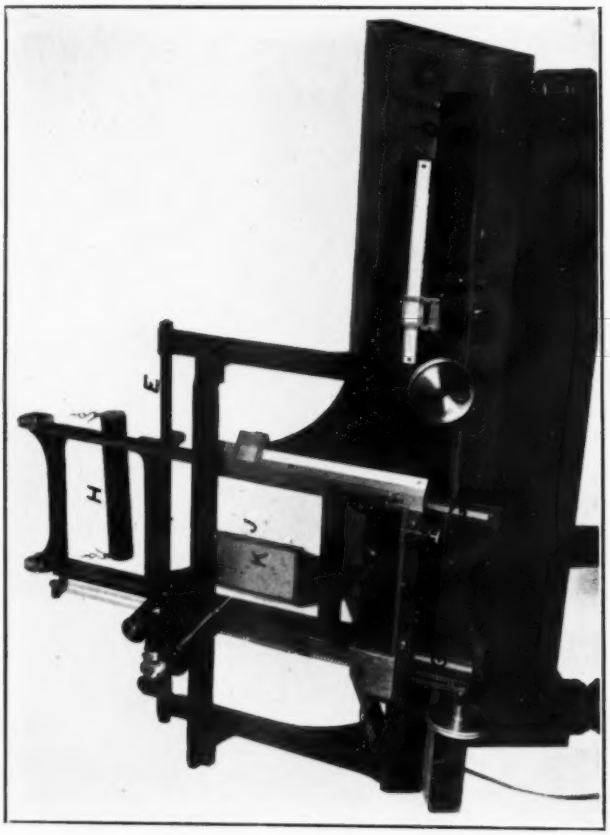
PLATE II.



INSTRUMENT FOR MEASURING PHOTOGRAPHIC PLATES

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VOL. XII. APRIL, 1918. NO. 4

MEASUREMENT OF RADIAL VELOCITIES OF STARS BY MEANS OF THE OBJECTIVE PRISM SPECTROGRAPH

BY T. S. H. GRAHAM.

HISTORICAL OUTLINE

IN 1842, Doppler advanced the theory that lines in the spectrum of a star, or other moving source of light, would be shifted to the red or blue, according as the source was receding from or approaching the observer. Six years later, Fizeau enunciated the principle now known as the Doppler-Fizeau Principle, upon which all spectrographic determinations of stellar velocities are based.

When the position of a line is known, and also its shifted position, the amount of shift can be read at once, and from this the radial velocity is computed according to a series of constants for the plate. Visual methods on the brighter stars were at first used by astronomers, such as Vogel and Keeler, but these results were very untrustworthy, owing to the difficulties of observation.

About 1890, astronomers discovered that, using the dry plate, photographs of the spectrum would give many measurable lines.

and to this work the largest telescopes, fitted with excellent slit spectrographs, have since been applied with splendid success. The accuracy now obtained with the best instruments leaves a probable error in a star with good lines of less than one-tenth of a kilometer, so the results obtained are now exceedingly accurate.

Results of this accuracy would seem to cover the field of stellar motions, but only a single star with its comparison spectrum can be photographed on a plate, and as some exposures require upwards of an hour, even with the number of instruments now in use, the obtaining of results is a slow process. Again, owing to the great loss of light in exposures with the slit spectrograph, stars below the sixth magnitude cannot, so far, be photographed, even by the largest telescopes and best spectrographs. Here we see the real limit of radial velocity determinations with the slit spectrograph.

In recent years a knowledge of the radial velocities of faint stars has become a very pressing need. Astronomers feel this lack greatly in solving such problems as the determination of the sun's way, and the relation between stellar velocity and stellar type. Using the objective prism, spectra have been photographed at Harvard of stars down to the tenth and eleventh magnitudes, and in addition, all the stars in the photographed region are present on the same plate. The difficulty in this method is to get comparison lines, as a comparison spectrum cannot be photographed beside the spectrum, as in the case of the slit spectrograph. At the request of Professor E. C. Pickering* of Harvard, Professor R. W. Wood of Baltimore made an investigation and found that if light is passed through a filter of neodymium chloride, a narrow absorption neodymium line is present in the spectrum at λ 4272. With this line for comparison, spectra photographed with the objective prism may be utilized to determine radial velocities of stars down to the tenth and eleventh magnitudes at least. The problem now becomes one of accuracy, and if dependable results can be obtained by this method, not only can much time be saved, but also many more stellar spectra of faint stars can be measured.

*Harvard Circular, No. 154.

Slit and Objective Spectrographs Compared.

In the slit spectrograph the light from the star is first collected by the telescope to which the spectrograph is attached. The slit must lie very accurately in the focal plane of this telescope objective, so that as much as possible of the light may be used. A collimating lens is so placed that the slit is also in its focal plane hence the light from the slit source will be parallel after passing through this collimating lens. These rays then pass through a prism, or system of prisms, and the spectrum of the stellar light is photographed by a specially constructed camera attachment. We see then that only that portion of the stellar light which falls on the slit can be utilized in this form of instrument. By covering a portion of the slit during exposure, however, and then exposing this portion to any desired source, a suitable comparison spectrum can be readily obtained.

With the objective prism instrument the star itself serves as the source, and as it is at an infinite distance, the rays are already parallel and no collimating lens is required. These parallel rays are allowed to fall directly on a prism, or set of prisms, placed over the objective of the telescope. A star, however, being a point source, will only give a point image in any particular color. To give breadth to the spectrum, the refracting edge of the prism is set parallel to the equator, and then the clock of the telescope is regulated to run either a trifle slow or fast. If a ray-filter is placed in the path of the rays before entering the prism, we get an absorption line which will not be shifted, and hence which will serve as a comparison line in spectra taken in this manner. Owing to the fact that the star itself acts as the source, there is a great saving in light; also the spectrum of any star which lies in the field of view of the telescope will be impressed on the plate. If the objective prism used covers the whole aperture, we get the maximum utility of the star's light. Such an arrangement has enabled astronomers to obtain spectra of stars down to the tenth and eleventh magnitudes. On account of the small angle of the prism and consequent small dispersion, even with prisms made of highly dispersive

material, the great accuracy obtained with slit instruments cannot be hoped for from objective prism spectra.

Instruments.

The plate measured in the present investigation was taken with the 16-inch Metcalf Refracting Telescope of Harvard University, fitted with a specially-corrected objective doublet, which makes this instrument one of the most efficient for work of this nature. The plates used are curved to correct for curvature. This is accomplished by exhausting the air at the back of the plate. A 9-inch finder is attached for guiding purposes. The mechanical corrections and devices for guiding the telescope are so efficient that circular images are still obtained with exposures of an hour or more.

The photographic doublet is made of dense flint glass which, being thin, reduces curvature errors to a minimum. Other errors, such as astigmatism and coma, are also corrected by theoretical and mechanical means.

The ray-filter used was neodymium chloride, which produces a narrow neodymium line at λ 4272.80, well situated for comparison purposes.

The plate measured was taken at Harvard in March, 1915, being one of a series covering the entire available sky. Its centre is at right ascension 12 h. 36 m., declination 40 deg. 30 min., all the stars photographed belonging to the constellation Canes Venatici.

Measuring Microscope.

The instrument used is one specially adapted for work of this kind. The frame was designed and constructed in the workshop of Harvard Observatory, and the microscope made by the Bausch and Lomb Company. A photograph of the complete instrument is shown here (Plate II.). The position of the plate *AB* is controlled in the horizontal plane by the screw *C*, motion taking place along the runway on two bars, *D* and *E*. Motion up and down is produced by the screw *F*, the carriage sliding along the runway *G*, *G*. The weight *H* assures that there is no lost motion when the

plate is being raised along *G*, *G*. The field is illuminated by a high-power incandescent globe *J*, behind a frosted glass plate *K*. This glass prevents all glare and provides a uniform, fairly bright illumination of the field of view of the microscope. The microscope is fitted with an achromatic objective and positive eyepiece. The focussing of the objective is controlled by the ordinary milled screwheads. The cross-hairs of the eyepiece must be kept carefully focussed. An accurate focus on any spectrum was obtained quite rapidly and with little inconvenience, and there was a splendid field of view for all measurements.

With the draw-tube as short as possible, the magnification of the objective is 3½ (f = 2.5 in.), while that of the eyepiece is 12½, hence the effective magnification of the instrument is about 44 diameters.

The measurements are made by means of a filar micrometer, which fits into the draw-tube of the microscope, being secured by a set-screw. One revolution of the micrometer screw moves the wire .5 mm. across the field. The head of the screw is divided into 50 parts, each .01 mm. One-tenth of this interval can then be estimated, giving us readings to the third decimal place of a millimeter. A scale, ruled in intervals of .5 mm., and placed in the field, serves for counting the full revolutions of the screw.

In making measurements, the plate was first placed with the red end of the spectrum to the right. Four settings were made on each line, two with the vertical hair approaching from the left, and two from the right. The plate was then reversed and the operation repeated. All readings were corrected to make the position of the neodymium line zero, and the positions of other lines were recorded in scale divisions. Each reading is therefore the average of eight settings, the neodymium line being an arbitrary zero.

Method of Computation.

We know* that for a shift of 1 Angstrom the linear velocity is given by V_1 where

$$V_1 = \pm 299860/\lambda,$$

*See W. W. Campbell, "Stellar Motions," p. 17.

+ being for shifts toward the red, *i.e.*, for velocities of recession
— being for shifts toward the blue, *i.e.*, for velocities of approach.
The velocity for any shift $\Delta\lambda$ must be proportional to this, or

$$V = \pm V_1 \Delta\lambda.$$

Using Table II., "Stellar Motions," p. 68, we can find the equivalent radial velocity for any λ. Hence all that we must find is the shift of a line $\Delta\lambda$, in terms of wave-lengths.

The measures of the position of star and of the neodymium comparison lines are linear, and before radial velocities can be determined, these must be reduced to wave lengths. To do this we have Hartmann's interpolation formula,*

$$\lambda = \lambda_0 - \frac{c}{n - n_0},$$

where λ = the effective wave length of the line,
n = the micrometer reading,
and λ_0, c, n_0 are constants for the plate.
To determine these three constants, three equations are necessary.

$$\lambda_1 = \lambda_0 - \frac{c}{n_1 - n_0},$$

$$\lambda_2 = \lambda_0 - \frac{c}{n_2 - n_0},$$

$$\lambda_3 = \lambda_0 - \frac{c}{n_3 - n_0}.$$

From these, by subtraction and transposition,

$$n_0 = \frac{(\lambda_2 - \lambda_1)(n_3 - n_1) n_2 - (\lambda_3 - \lambda_1)(n_2 - n_1) n_3}{(\lambda_2 - \lambda_1)(n_3 - n_1) - (\lambda_3 - \lambda_1)(n_2 - n_1)};$$

$$\lambda_0 = \frac{\lambda_3 (\lambda_2 - \lambda_1)(n_3 - n_1) - \lambda_2 (\lambda_3 - \lambda_1)(n_2 - n_1)}{(\lambda_2 - \lambda_1)(n_3 - n_1) - (\lambda_3 - \lambda_1)(n_2 - n_1)};$$

$$c = (\lambda_1 - \lambda_0)(n_1 - n_0),$$
$$= (\lambda_2 - \lambda_0)(n_2 - n_0),$$
$$= (\lambda_3 - \lambda_0)(n_3 - n_0).$$

To get the three equations for determining these constants, we need the wave-length and position of three unshifted lines, *i.e.*, three lines of the comparison spectrum. Such are not available

*Astrophysical Journal, vol. 8, p. 218.

here, hence we take the three hydrogen lines $H\gamma$, λ 4340.66; $H\delta$, λ 4101.85; $H\epsilon$, λ 3970.18. In using these lines, the assumption is made that the shifts are all equal, instead of being proportional to λ, and since the shifts are so small numerically, the error introduced by doing so will be small, although it is present and unavoidable.

The values of n_1, n_2, n_3 were obtained by measuring the positions of $H\gamma$, $H\delta$, $H\epsilon$, in each of 10 stars containing these lines. Hence, since each reading is the average of 8 settings on the line, we see that the values of n_1, n_2, n_3, are the means of 80 readings, which should give us fairly accurate values.

Having obtained these constants by substitution in the original equation, a check on the work is obtained which is very valuable.

The position of N, the neodymium line, was also measured in each case, and by this check we find where the mean position of N for these 10 stars would be, assuming the H lines to be fixed. But N is fixed, so changing the sign, we have the shift of the mean of the hydrogen lines for these readings. Hence we can apply this correction to our subsequent velocities. This is the correction marked V_a.

In measuring the positions of the three lines, $H\delta$ was taken as arbitrary zero, and the others corrected for this. We must now get our constants with respect to $N\ \lambda\ 4272.80$ as zero, instead of $H\delta$. In doing this, we must also remember the solar correction. (This will be explained under corrections.) Since

$$\lambda = \lambda_0 - \frac{c}{n - n_0},$$

$$\therefore \frac{d\lambda}{dn} = -\frac{c}{(n - n_0)^2};$$

also $V = \pm V_r \Delta\lambda$, ("Stellar Motions," p. 17),

$$\text{and } \frac{dv}{dn} = \frac{dv}{d\lambda} \cdot \frac{d\lambda}{dn}.$$

But the value of $\frac{dv}{d\lambda}$ for any value of λ is given.* Since we

*"Stellar Motions," Table II., p. 68.

want N λ 4272.80 as our point of reference, this value of λ should be used.

I here insert the actual computation of normal N for the plate used, as best explaining the method of computation.

$$d\lambda = -\frac{c}{(n - n_0)^2}\, dn, \text{ at } \lambda\ 4272{\cdot}80$$

$\log\ n - n$	1.1001994
$\log\ (n - n_0)^2$	3.2003988
$\log\ c$	4.9823012
$\log \frac{d\lambda}{dn}$	1.7819024
$\log\ 70.17$	1.8461515
$\log \frac{dv}{dn}$	3.6280539

$\therefore \frac{dv}{dn} = -4247$ km. at N.

But reduction to sun $= -2.8$ km. (see corrections),

$= +.001$ scale divisions.

$N - H\delta = 3.041$ scale divisions (assuming mean velocity of 10 stars to be 0. The correction V_a allows for this assumption). $\therefore N - H\delta = 3.042$ scale divisions for a stationary spectrum. Now, if we subtract this quantity from n_0 already obtained, we get the true value of n_0 with N as zero, and a stationary spectrum as our basis instead of a shifted spectrum.

We must now find the normal positions of all lines used in the computations. From Hartmann's formula we have

$$n - n_0 = -\frac{c}{\lambda - \lambda_0},$$

hence for any desired value of λ, we can calculate the normal value of n. Then, knowing the unshifted position of a line from computation, and the shifted position from observation, the shift can be at once found in scale divisions.

To reduce these shifts in scale divisions to linear velocities, we have but to follow the method used for λ 4272.80. Thus we

have the value $\frac{d\,v}{d\,n}$, *i.e.*, the radial velocity for a shift of 1 scale division, for any desired λ.

CORRECTIONS USED.

(1) The correction V_a, due to the fact that we must assume the mean velocity of 10 stars to be 0 in order to change from a shifted to a stationary spectrum, whereas the check developed from Hartmann's formula shows this to be slightly in error, has been already explained. The value of this correction for the first set of measures was $V_a = +2.8$ km., per sec., and hence was practically negligible.

(2) The radial velocity of a star found as above gives us the value with respect to the observer. That this may be comparable with values obtained elsewhere, it must be reduced to the sun as the point of reference. To do this, three variables must be removed.

(a) Correction for the velocity of the earth in its orbit about the sun.

(b) Correction for the velocity of the earth caused by the revolution of the earth and moon about their common centre of gravity.

(c) Correction for the diurnal rotation of the earth on its axis.

Corrections (b) and (c) are never more than $\pm$ .5 km. and here are omitted entirely.

To compute correction (a), we have

$V_s = - V_a \sin (\lambda - \odot + i) \cos \beta$ ("Stellar Motions" page 65)

where V_a is the earth's velocity in its orbit in kilometers per sec.

λ is the longitude of the star,

β is the latitude of the star,

$\odot$ is the sun's longitude at the time of observation.

$(90 - i)$ is the angle between the tangent to the earth's orbit and the radius vector drawn to the point of tangency.

Now V_a and i have been tabulated* as functions of $\odot$, hence

*See "Stellar Motions," Table III., p. 68.

obtaining ☉ from the Ephemeris, the correction is obtained at once.

λ and β were calculated for the centre of the plate, and this correction was applied for the whole plate. The error in this method of procedure will be quite negligible.

Errors, Defects, and Approximations.

The curvature of the spectral lines, while corrected as far as possible by exhausting the air back of the plates, was not entirely absent, and in some stars this made it quite difficult to judge what portion of the line should be set on.

A-type stars, with a few of type *F*, were practically the only stars available for computing the constants of the plate, as in other types the hydrogen lines soon fade out. Thus only part of the plate is represented in the computed constants, but as these stars are fairly well distributed, the error on this account is probably small.

In some of the *A*-type stars the hydrogen lines $H\delta$ and $H\epsilon$ are very broad, and much difficulty was found in setting accurately on these broad lines. A lower power microscope might give slightly better results than those obtained.

The approximation implied in assuming, in the computation, that the shift of the hydrogen lines is the same for all instead of being proportional to the wave-length, has been mentioned already. This defect in theory apparently is unavoidable, and yet may, or may not, mar the results to a considerable extent.

The approximation allowed for in Correction (1), *i.e.*, of assuming the radial velocity of 10 stars to be 0, and then applying a check from Hartmann's formula, is a rather delicate matter and here considerable error may be present. The extent of this error depends on the accuracy of the constants of the plate.

The dispersion of a plate 8 x 10 inches in size usually varies considerably, yet here we use the mean as obtained from 10 stellar measures. This defect may also be responsible for quite an appreciable error in results obtained by this method.

On account of the small dispersion which must be used in

the objective prisms, and the consequent short spectra which must be measured, the method is inherently an exacting one.

But the accidental error of an observer in setting on the lines is probably the most fruitful source of errors, and to a great extent the success or failure of the method must depend on minimizing errors of this nature.

Notes.

The stars were identified by comparing the plate with the *BD* Charts, and the numbers are given in Table I.

The positions of the stars for 1900 are also given. All the stars measured are in the constellation Canes Venatici, the centre of the plate being at R. A. 12 h. 36 m., Dec. 40° 30′.

The classification of the spectra and the magnitudes were obtained from Harvard Observatory.

Four distinct sets of measurements of the plate were made, the results being as tabulated. The position of *N* is not given, as all results were corrected to make this line zero.

Table I.—List of Stars Measured.

Designation	B.D. No.	R.A. 1900	Decl. 1900	Magnitude	Spectrum
198′	+42 2307	12h.22.6m.	+41 55	6.85	F_5
γ	+42 2343	44.8m.	+42 37	8.0	A_2
1	+40 2537	21.1m.	+40 27	8.2	F_2
2	+40 2542	25.3m.	+39 49	7.62	F_8
3	+40 2551	30.9m.	+40 14	7.17	A_0
4	+39 2540	32.8m.	+39 13	7.29	F_5
5	+40 2558	34.0m.	+39 51	7.37	A_0
6	+41 2337	47.2m.	+40 47	8.2	F_0
9	+41 2312	33.9m.	+41 25	6.29	A_1
10	+40 2570	40.3m.	+39 50	5.97	F_8
11	+40 2543	26.2m.	+40 8	6.81	K_0
12	+41 2298	25.5m.	+41 22	8.4	K_2
13	+41 2302	28.6m.	+41 18	8.1	G_0
14	+41 2308	31.4m.	+41 8	7.66	K_0
15	+40 2557	33.4m.	+40 31	8.4	F_5
β	+42 2321	29.0m.	+41 54	4.32	G_0
17	+40 2552	31.4m.	+40 4	8.8	F_5
18	+41 2313	34.4m.	+41 33	8.2	K_1
19	+41 2320	36.7m.	+41 8	7.68	K_0
20	+41 2318	36.1m.	+41 5	8.21	G_0

TABLE II.—CONSTANTS FOR PLATE.

Plate M. C. 8262, from the mean of 10 stars, at λ 4272·80

$n_0 = 39{\cdot}828$

$\lambda_0 = 1862{\cdot}37$

$\log c = 4{\cdot}9823012_n$

Correction V_a = + 2·8 km. per sec. in Set I.
= + 7·0 km. per sec. in Set II.

Correction V_s = − 2·8 km per sec.

CONSTANTS FOR THE DIFFERENT VALUES OF λ

Line	Hγ	Fe_1	Fe_2	Nd.	Ca	Hδ	Hε
Value λ	4340.66	4325.94	4308.08	4272.80	4226.90	4101.85	3970.18
Nor. position Set I.	1 089	.857	.573	.000	−.775	−3 041	−5.720
" " Set II.	1.088	.856	.572	.000	−.776	−3.042	−5.721
V_s in km.	69.1	69.3	69·6		70.9	73.1	75.5
$\frac{dv}{dn}$ in km.	4420	4381	4336		4129	3818	3494

TABLE III.—RADIAL VELOCITIES, FIRST SET.

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
198′	Hγ	1.087	−.002	− 8.8 km.	− 8.8 km.
	Hδ	−3.044	−.003	−11.5	−11.5
	Hε	−5.722	−.002	− 7.0	− 7.0
					Mean − 9.1
γ	Hγ	1.072	−.017	−75.1	−75.1
	Hδ	−3.059	−.018	−68.7	−68.7
	Hε	−5.737	−.017	−59.3	−59.3
					Mean −67.7
1	Hγ	1.077	−.012	−53.0	−53.0
	Hδ	−3.054	−.013	−49.6	−49.6
	Hε	−5.732	−.012	−42.0	−42.0
					Mean −48.2
2	Hγ	1.096	+.007	+30.9	+30.9
	Hδ	−3.035	+.006	+22.9	+22.9
	Hε	−5.713	+.007	+24.5	+24.5
					Mean +26.1
3	Hγ	1.091	+.002	+ 8.8	+ 8.8
	Hδ	−3.040	+.001	+ 3.8	+ 3.8
	Hε	−5.718	+.002	+ 7.0	+ 7.0
					Mean + 6.5

TABLE III.—*(Continued)*

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
4	Hγ	1.108	+.019	+84.0	+84.0
	Hδ	—3.023	+.018	+69.8	+69.8
	Hε	—5.701	+.019	+66.3	+66.3
				Mean	+73.3
5	Hγ	1.086	—.003	—13.3	—13.3
	Hδ	—3.045	—.004	—15.3	—15.3
	Hε	—5.724	—.004	—14.0	—14.0
				Mean	—14.2
6	Hγ	1.080	—.009	—39.8	—39.8
	Hδ	—3.051	—.010	—38.4	—38.4
	Hε	—5.729	—.009	—31.4	—31.4
				Mean	—36.5
9	Hγ	1.088	—.001	— 4.4	— 4.4
	Hδ	—3.043	—.002	— 7.6	— 7.6
	Hε	—5.721	—.001	— 3.5	— 3.5
				Mean	— 5.2
10	Hγ	1.111	+.022	+97.2	+97.2
	Hδ	—3.020	+.021	+80.2	+80.2
	Hε	—5.698	+.022	+76.8	+76.8
				Mean	+84.7
11	Hγ	1.093	+.004	+17.7	+17.7
	Fe₁	.862	+.005	+21.9	+21.9
	Ca	— .769	+.006	+24.8	+24.8
				Mean	+21.5
12	Fe₂	.565	—.008	—34.7	—34.7
13	Hγ	1.082	—.007	—30.9	—30.9
	Hδ	—3.047	—.006	—20.8	—20.8
				Mean	—25.8
14	Fe₁	.848	—.009	—39.4	—39.4
	Ca	— .784	—.009	—37.2	—37.2
				Mean	—38.3
15	Hγ	1.089	.000	0.0	0.0
β	Hγ	1.090	+.001	+ 4.4	+ 4.4
	Fe₂	.572	—.001	— 4.3	— 4.3
				Mean	0.0

TABLE III. (*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
17	Hγ	1.097	+.008	+35.3	+35.3
	Hδ	—3.036	+.005	+19.1	+19.1
				Mean	+27.2
18	Hγ	1.093	+.004	+17.6	+17.6
	Ca	— .772	+.003	+12.4	+12.4
				Mean	+15.0
19	Hγ	1.085	—.004	—17.6	—17.6
	Fe_1	.851	—.006	—26.3	—26.3
	Ca	— .780	—.005	—20.6	—20.6
				Mean	—21.5
20	Hγ	1.082	—.007	—30.9	—30.9
	Fe_1	.849	—.008	—35.0	—35.0
	Ca	— .783	—.008	—33.0	—33.0
				Mean	—33.0

TABLE IV.—RADIAL VELOCITIES, SECOND SET.
For Constants for Plate see Table II.

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
198′	Hγ	1.086	—.002	— 8.9	— 4.7
	Hδ	—3.045	—.003	—11.5	— 7.3
	Hε	—5.723	—.002	— 7.0	— 2.8
				Mean	— 4.9
γ	Hγ	1.076	—.012	—53.0	—49.8
	Hδ	—3.055	—.013	—49.5	—45.3
	Hε	—5.733	—.012	—41.9	—37.7
				Mean	—43.9
1	Hγ	1.074	—.014	—61.9	—57.7
	Hδ	—3.029	—.013	—49.6	—45.4
	Hε	—5.707	—.014	—48.9	—44.7
				Mean	—49.3
2	Hγ	1.096	+.008	+35.4	+39.6
	Hδ	—3.049	+.007	+26.7	+30.9
	Hε	—5.729	+.008	+27.9	+32.1
				Mean	+34.2
3	Hγ	1.089	+.001	+ 4.4	+ 8.8
	Hδ	—3.042	+.000	+ 0.0	+ 4.2
	Hε	—5.720	+.001	+ 3.5	+ 7.7
				Mean	+ 6.8

TABLE IV.—(*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
4	Hγ	1.105	+.017	+75.1	+79.3
	Hδ	—3.026	+.016	+61.0	+65.2
	Hε	—5.704	+.017	+59.5	+63.7
					Mean 69.4
5	Hγ	1.082	—.006	—26.5	—22.3
	Hδ	—3.049	—.007	—26.7	—22.5
	Hε	—5.727	—.006	—20.9	—16.7
					Mean —20.5
6	Hγ	1.078	—.010	—44.2	—40.0
	Hδ	—3.053	—.011	—41.9	—37.7
	Hε	—5.731	—.010	—34.9	—30.7
					Mean —36.1
9	Hγ	1.092	+.004	+17.7	+21.9
	Hδ	—3.039	+.003	+11.4	+15.6
	Hε	—5.717	+.004	+14.0	+18.2
					Mean +18.4
10	Hγ	1.107	+.019	+84.0	+88.2
	Hδ	—3.024	+.018	+69.8	+74.0
	Hε	—5.702	+.019	+66.3	+70.5
					Mean +77.5
11	Hγ	1.095	+.007	+30.9	+35.1
	Fe_1	.861	+.005	+21.9	+26.1
	Ca	— .768	+.008	+33.0	+37.2
					Mean +33.2
12	Fe_2	.559	—.013	—55.9	—51.7
13	Hγ	1.081	—.007	—30.9	—26.7
	Hδ	—3.045	—.003	—11.4	— 7.2
					Mean —17.0
14	Fe	.848	—.008	—35.0	—30.8
	Ca	— .782	—.006	—24.7	—20.5
					Mean —25.6
15	Hγ	1.088	.000	0.0	+ 4.2
β	Hγ	1.089	+.001	+ 4.4	+ 8.6
	Fe_2	.574	+.002	+ 8.7	+12.9
					Mean +10.7

TABLE IV.—(*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
17	Hγ	1.098	+.010	+44.2	+48.4
	Hδ	—3.032	+.010	+38.2	+42.4
				Mean	+45.4
18	Hγ	1.090	+.002	+ 8.8	+13.0
	Ca	— .778	+.002	+ 8.2	+12.4
				Mean	+12.7
19	Hγ	1.085	—.003	—13.2	— 9.0
	Fe_1	.851	—.005	—21.9	—17.7
	Ca	— .779	—.003	—12.4	— 8.2
				Mean	—11.6
20	Hγ	1.082	—.006	—26.4	—22.1
	Fe_1	.850	—.006	—26.3	—22.1
	Ca	— .774	—.008	—32.9	—28.7
				Mean	—24.3

TABLE V.—RADIAL VELOCITIES, THIRD SET.

Constants for Plate the same as in Second Set

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
198′	Hγ	1.085	—.003	—13.2	— 9.0
	Hδ	—3.046	—.004	—15.3	—11.1
	Hε	—5.724	—.003	—10.5	— 6.3
				Mean	— 8.8
γ	Hγ	1.079	—.009	—39.8	—35.6
	Hδ	—3.052	—.010	—38.2	—34.0
	Hε	—5.731	—.009	—31.4	—27.2
				Mean	—32.3
1	Hγ	1.076	—.012	—53.0	—49.8
	Hδ	—3.055	—.013	—49.6	—45.4
	Hε	—5.733	—.012	—41.5	—37.3
				Mean	—44.2
2	Hγ	1.097	+.009	+39.8	+44.0
	Hδ	—3.034	+.008	+30.6	+34.8
	Hε	—5.712	+.009	+31.4	+35.6
				Mean	+38.2

TABLE V.—(*Continuea*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
3	Hγ	1.093	+.005	+22.1	+26.3
	Hδ	—3.038	+.004	+15.2	+19.4
	Hε	—5.716	+.005	+17.5	+21.7
				Mean	+22.5
4	Hγ	1.105	+.017	+75.1	+79.3
	Hδ	—3.026	+.016	+61.0	+65.2
	Hε	—5.704	+.017	+59.3	+63.5
				Mean	+69.3
5	Hγ	1.080	—.008	—35.4	—31.2
	Hδ	—3.051	—.009	—34.4	—30.2
	Hε	—5.729	—.008	—28.0	—23.8
				Mean	—28.4
6	Hγ	1.081	—.007	—30.9	—26.7
	Hδ	—3.050	—.008	—30.6	—26.4
	Hε	—5.728	—.007	—24.5	—20.3
				Mean	—24.5
9	Hγ	1.093	+.005	+22.0	+26.2
	Hδ	—3.038	+.004	+15.3	+19.5
	Hε	—5.716	+.005	+17.5	+21.7
				Mean	+22.5
10	Hγ	1.103	+.015	+66.3	+70.5
	Hδ	—3.028	+.014	+53.4	+57.6
	Hε	—5.706	+.015	+52.3	+56.5
				Mean	+61.5
11	Hγ	1.094	+.006	+26.5	+30.7
	Fe_1	.860	+.004	+17.5	+21.7
	Ca	— .769	+.007	+28.9	+33.1
				Mean	+28.5
12	Fe_2	.566	—.006	—26.0	—21.8
13	Hγ	1.081	—.007	—30.9	—26.7
	Hδ	—3.048	—.006	—20.8	—16.6
				Mean	—21.6
14	Fe	.849	—.007	—30.7	—26.5
	Ca	— .781	—.005	—20.6	—16.4
				Mean	—21.5
15	Hγ	1.091	+.003	+13.3	+17.5

TABLE V.—(*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
β	Hγ	1.093	+.005	+22.1	+26.3
	Fe_2	.574	+.002	+ 8.7	+12.9
				Mean	+19.6
17	Hγ	1.097	+.009	+39.8	+44.0
	Hδ	—3.037	+.005	+19.1	+23.3
				Mean	+33.6
18	Hγ	1.093	+.005	+22.1	+26.3
	Ca	— .767	+.009	+37.2	+41.4
				Mean	+33.8
19	Hγ	1.086	—.002	— 8.8	— 4.6
	Fe_1	.853	—.003	—13.1	— 8.9
	Ca	— .781	—.005	—20.6	—16.4
				Mean	—10.0
20	Hγ	1.085	—.003	—13.3	— 9.1
	Fe_1	.850	—.006	—26.3	—22.1
	Ca	— .779	—.003	—12.4	— 8.2
				Mean	—13.1

TABLE VI.—RADIAL VELOCITIES, FOURTH SET.

Constants for plate, the same as in Second Set.

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
198′	Hγ	1.088	.000	0.0	+ 4.2
	Hδ	—3.043	—.001	— 3.8	+ .4
	Hϵ	—5.721	.000	0.0	+ 4.2
				Mean	+ 2.9
γ	Hγ	1.077	—.011	—48.6	—44.4
	Hδ	—3.054	—.012	—45.8	—41.6
	Hϵ	—5.732	—.011	—38.4	—34.2
				Mean	—40.1
1	Hγ	1.074	—.014	—61.9	—57.7
	Hδ	—3.057	—.015	—57.3	—53.1
	Hϵ	—5.735	—.014	—48.9	—44.7
				Mean	—51.8

TABLE VI.—(*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
2	Hγ	1.094	+.006	+26.5	+30.7
	Hδ	—3.037	+.005	+19.1	+23.3
	Hε	—5.715	+.006	+21.0	+25.1
					Mean—+26.4
3	Hγ	1.091	+.003	+13.3	+17.5
	Hδ	—3.040	+.002	+ 7.6	+11.8
	Hε	—5.718	+.003	+10.5	+14.7
					Mean +14.7
4	Hγ	1.104	+.016	+70.7	+74.9
	Hδ	—3.027	+.015	+58.0	+62.2
	Hε	—5.705	+.016	+55.9	+60.1
					Mean +65.7
5	Hγ	1.082	—.006	—26.5	—22.3
	Hδ	—3.049	—.007	—26.7	—22.5
	Hε	—5.727	—.006	—21.0	—16.8
					Mean —20.5
6	Hγ	—1.083	—.005	—22.1	—17.9
	Hδ	—3.048	—.006	—22.9	—18.7
	Hε	—5.726	—.005	—17.5	—13.3
					Mean 16.6
9	Hγ	1.089	+.001	+ 4.4	+ 8.6
	Hδ	—3.042	+.000	+ 0.0	+ 4.2
	Hε	—5.720	+.001	+ 3.5	+ 7.7
					Mean + 6.8
10	Hγ	1.003	+.015	+66.3	+70.5
	Hδ	—3.028	+.014	+53.5	+57.7
	Hε	—5.706	+.015	+52.3	+56.5
					Mean 61.6
11	Hγ	1.095	+.007	+30.9	+35.1
	Fe_1	.862	+.004	+17.5	+21.7
	Ca	— .767	+.008	+33.0	+37.2
					Mean +31.3
12	Fe_2	.571	—.002	— 8.7	— 4.3
13	Hγ	1.084	—.004	—17.7	—13.5
	Hδ	—3.047	—.005	—19.9	—14.9
					Mean —14.2

TABLE VI.—(*Continued*)

Star	Line	Mean Reading	Shift	Rad. Vel. (km.)	Corrected R.V. (km.)
14	Fe	.849	—.007	—30.7	—26.5
	Ca	— .782	—.006	—24.7	—20.5
				Mean	—23.5
15	Hγ	1.090	+.002	+ 8.8	+13.0
β	Hγ	1.087	—.001	— 4.4	— .2
	Fe_2	.575	+.003	+13.0	+17.2
				Mean	+ 8.5
17	Hγ	1.095	+.007	+30.9	+35.1
	Hδ	—3.034	+.008	+30.5	+34.7
				Mean	+34.9
18	Hγ	1.095	+.007	+30.9	+35.1
	Ca	— .769	+.007	+28.8	+33.0
				Mean	+34.0
19	Hγ	1.084	—.004	—17.7	—13.5
	Fe_1	.852	—.004	—17.5	—13.3
	Ca	— .778	—.002	— 8.2	— 4.0
				Mean	—10.3
20	Hγ	1.085	—.003	—13.3	— 9.1
	Fe_1	.853	—.003	—13.1	— 8.9
	Ca	— .780	—.004	—16.5	—12.3
				Mean	—10.1

TABLE VII.—SUMMARY OF RESULTS.

Star	Sp.	Mag.	Set	Hγ	Fe_1	Fe_2	Ca	Hδ	Hε	Mean V. (km.)
198′	F8	6.85	1	— 8.8				—11.5	— 7.0	— 9.1
			2	— 4.7				— 7.3	— 2.8	— 4.9
			3	— 9.0				—11.1	— 6.3	— 8.8
			4	+ 4.2				+ 0.4	+ 4.2	+ 2.9
								Mean of all		— 5.0
γ	A2	8.0	1	—75.1				—68.7	—59.3	—67.7
			2	—49.8				—45.3	—37.7	—43.9
			3	—35.6				—34.0	—27.2	—32.3
			4	—44.4				—41.6	—34.2	—40.1
								Mean of all		—46.0

TABLE VII.—(*Continued*)

Star	Sp.	Mag.	Set	H_γ	Fe_1	Fe_2	Ca	$H\delta$	$H\varepsilon$	Mean V. (km.)
1	F_2	8.2	1	—53.0				—49.6	—42.0	—48.2
			2	—57.7				—45.4	—44.7	—49.3
			3	—49.8				—49.6	—41.5	—44.2
			4	—57.7				—53.1	—44.7	—51.8
									Mean of all	—48.4
2	F_8	7.62	1	+30.9				+22.9	+24.5	+26.1
			2	+39.6				+30.9	+32.1	+34.2
			3	+44.0				+34.8	+35.6	+38.1
			4	+30.7				+23.3	+25.1	+26.4
									Mean of all	+31.2
3	A_0	7.17	1	+ 8.8				+ 3.8	+ 7.0	+ 6.5
			2	+ 8.6				+ 4.2	+ 7.7	+ 6.8
			3	+26.3				+19.4	+21.7	+22.5
			4	+17.5				+11.8	+14.7	+14.7
									Mean of all	+12.6
4	F_2	7.29	1	+84.0				+69.8	+66.3	+73.3
			2	+79.3				+65.2	+63.7	+69.4
			3	+79.3				+65.2	+63.5	+69.3
			4	+74.9				+62.2	+60.1	+65.7
									Mean of all	+69.4
5	A_0	7.37	1	—13.3				—15.3	—14.0	—14.2
			2	—22.3				—22.5	—16.7	—20.5
			3	—31.2				—30.2	—23.8	—28.4
			4	—22.3				—22.5	—16.8	—20.5
									Mean of all	—20.9
6	F_0	8.2	1	—39.8				—38.2	—31.4	—36.5
			2	—40.0				—37.2	—30.7	—36.1
			3	—26.7				—26.4	—20.3	—24.5
			4	—17.9				—18.7	—13.3	—16.5
									Mean of all	—28.4
9	A_3	6.29	1	+ 4.4				+ 7.6	+ 3.5	+ 5.2
			2	+21.9				+15.6	+18.2	+18.4
			3	+26.2				+19.5	+21.7	+22.5
			4	+ 8.6				+ 4.2	+ 7.7	+ 6.8
									Mean of all	+13.2
10	F_8	5.97	1	+97.2				+80.2	+76.8	+75.4
			2	+88.2				+74.0	+70.5	+77.5
			3	+70.5				+57.6	+56.5	+61.5
			4	+70.5				+57.7	+56.5	+61.6
									Mean of all	+69.0

TABLE VII.—(*Continued*)

Star	Sp.	Mag.	Set	Hγ	Fe1	Fe2	Ca	Hδ	Hε	Mean V. (km.)
11	K0	6.81	1	+17.7	+21.9		+24.8			+21.5
			2	+35.1	+26.1		+37.2			+32.8
			3	+30.7	+21.7		+33.1			+28.5
			4	+35.1	+21.7		+37.2			+31.3
									Mean of all	+28.5
12	K2	8.4	1			−34.7				−34.7
			2			−51.7				−51.7
			3			−21.8				−21.8
			4			− 4.3				− 4.3
									Mean of all	−28.1
13	G0	8.1	1	−30.9				−20.8		−25.8
			2	−26.7				− 7.2		−17.0
			3	−26.7				−16.6		−21.6
			4	−13.5				−14.9		−14.2
									Mean of all	−19.6
14	K0	7.66	1		−39.4		−37.2			−38.3
			2		−30.8		−20.5			−25.6
			3		−26.5		−16.4			−21.5
			4		−26.5		−20.5			−23.5
									Mean of all	−27.2
15	F5	8.4	1	+ 0.0						+ 0.0
			2	+ 4.2						+ 4.2
			3	+17.5						+17.5
			4	+13.0						+13.0
									Mean of all	+ 8.7
β	G0	4.32	1	+ 4.4		− 4.3				+ 0.0
			2	+ 8.6		+12.9				+10.7
			3	+26.3		+12.9				+19.6
			4	− 0.2		+17.2				+ 8.5
									Mean of all	+ 9.7
17	F5	8.8	1	+35.3				+19.1		+27.2
			2	+48.4				+42.6		+45.2
			3	+44.0				+23.3		+33.6
			4	+35.1				+34.7		+34.9
									Mean of all	+35.2
18	K0	8.2	1	+17.6			+12.4			+15.0
			2	+13.0			+12.4			+12.7
			3	+26.3			+41.4			+33.8
			4	+35.1			+33.0			+34.0
									Mean of all	+23.9

TABLE VII.—(*Continued*)

Star	Sp.	Mag.	Set	$H\gamma$	Fe_1	Fe_2	Ca	$H\delta$	$H\varepsilon$	Mean V. (km.)
19	K_0	7.68	1	—17.7	—26.3		—20.6			—21.5
			2	— 9.0	—17.7		— 8.2			—11.6
			3	— 4.6	— 8.9		—16.4			—10.0
			4	—13.5	—13.3		— 4.0			—10.3
									Mean of all	—13.4
20	G_0	8.21	1	—30.9	—35.0		—33.0			—33.0
			2	—22.2	—22.1		—28.7			—24.3
			3	— 9.1	—22.1		— 8.2			—13.1
			4	— 9.1	— 8.9		—12.3			—10.1
									Mean of all	—20.1

CONCLUSIONS.

Kapteyn and Campbell have estimated that radial velocities could be computed, from photographs with the objective prism, having a probable error of about 10 km. per sec. An examination of the above summary would indicate a larger probable error than this in the results of the present investigation.

If the errors and defects previously mentioned could be eliminated wholly or even partially, it would appear quite reasonable to anticipate that results of great practical value might be obtained by this method. This is especially true when we remember that in the case of faint stars such as those dealt with, there is no other method available at present.

The majority of the stars measured are of spectral type F. As we advance to other types, the hydrogen lines gradually disappear, and as no other measurable lines appear in their place, this method is almost entirely confined to stars whose spectra contain hydrogen lines. On the plate used are several spectra fully as bright as those measured, but for which no results can be obtained owing to the absence of measurable lines. Hence it is apparent that while the objective prism may yet add greatly to our present knowledge of radial velocities, there still are a great many stars whose spectra can be photographed, but apparently not measured,

to give us even an approximate estimate of their radial velocities.

The above investigation was made at the University of Toronto, and I beg to thank Prof. C. A. Chant for suggesting it and for his continued assistance and encouragement. Acknowledgments are also due to Prof. E. C. Pickering, Director of the Harvard College Observatory, for supplying material and information regarding it.

CLINTON, ONT.

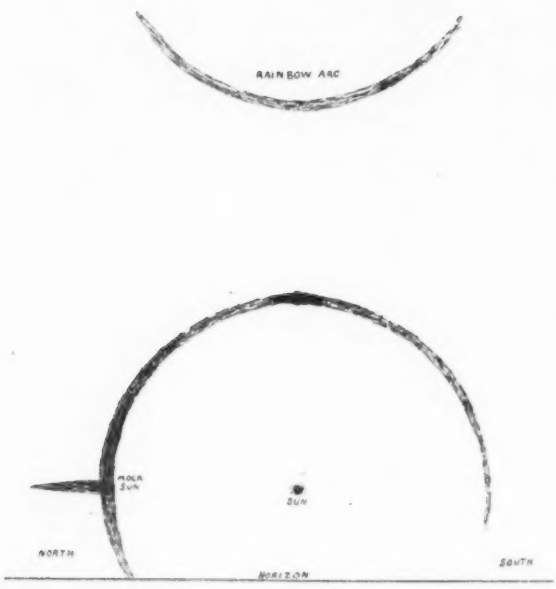
February, 1918.

THE SOLAR HALO OF FEBRUARY 4TH, 1918

I.—By J. P. Henderson

A SOLAR HALO was observed in the eastern part of Toronto on the morning of February 4th, 1918. It was first seen about 8.10 a.m. and was prominent till after 8.25 a.m. (E.S.T.), although by that time the sun was beginning to shine very brightly. The temperature was one of the lowest of the season, the mercury hovering at nearly 10° below zero F., and the sky was clear except for a few cirrus clouds in the west, but it had a rather milky appearance. The sun was about 10° above the horizon and getting just too bright to look at directly. The regular halo (primary circle) at about 23° from the sun appeared almost complete, but of the two parhelia or "mock-suns," only the one to the north of the sun was visible; the halo was much fainter toward the south and no trace of the other "mock-sun" could be detected. The one to the north was particularly bright with a beam of white light stretching out 10° or more at times to the northward of it; the part next the sun was rather chocolate or reddish colored which extended slightly along the halo itself. An intense part above the sun (the upper tangent arc) was fainter and uncolored. A "rainbow arc" was also present and seemed about 25° directly above the highest part of the primary circle. It was distinctly spectrum-colored, the red being on the lower and convex edge. Its curvature could only be conjectured to be about the same as that of the primary circle, as only about 25° of it was visible. The fine ice crystals in the upper atmosphere which were responsible for the halo phenomena probably also caused the slight milky appearance of the sky.

Another somewhat different solar halo was seen in the same place and about the same time of day as the above, on February 18th, 1918. The air was slightly misty but the sun was bright and the temperature only a few degrees above freezing. In this one, two "mock-suns" were present, one to the north and one to the south, the latter being rather the brighter, but neither attaining any considerable luminosity. They were both slightly



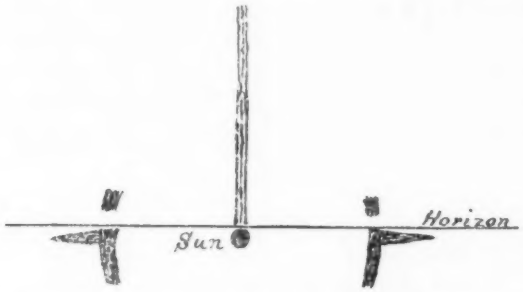
SOLAR HALO OBSERVED AT TORONTO ON FEBRUARY 4, 1918, 8.15 A.M. (E.S.T.) BY J. P. HENDERSON
Scale 0·1 in. = 2°

spectrum colored, red toward the sun. The main arch was very faint and could be detected only with difficulty, and the "rainbow arc" was not seen.

II.—By A. F. Hunter

There is a passage in Warburton Pike's book "The Barren Ground of Northern Canada," page 97, (Macmillan, London, 1892), in which he speaks of sun-dogs (*i. e.* "mock-suns") appearing above the horizon before the sun showed above it. Referring to the neighborhood of Great Slave Lake (about 63 degrees N. latitude) he says:—"The sunrise was often very beautiful and the effects of long duration, as the sun is close to the horizon a considerable time before he shows above it. . . . . .

Often a sun-dog is the first thing to appear and more or less of these attendants accompany the sun during his short stay above the horizon." Within a few days after my attention had been called to this passage, I had the good luck to witness a halo of the sun at Barrie, Ont., in which mock-suns seemed to be visible above the horizon before the sun appeared. On February 4th, 1918, at 7.30 a.m., (E.S.T.), what appeared to be two mock-suns were quite distinct before sunrise, as Warburton Pike describes. There was also a notable sun pillar, before sunrise, and after rising the sun was the centre of a cross. The mock-suns, however, on this occasion, were the more interesting parts of the



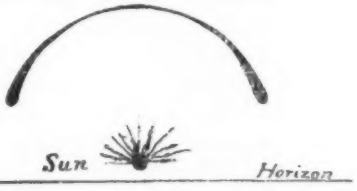
SOLAR HALO, FEBRUARY 4, 1918, 7.30 A.M. (E.S.T.) OBSERVED AT BARRIE BY A. F. HUNTER

The parts of the circle shown above the horizon had the appearance of two "mock-suns."

halo. First appearances and first impressions are not always safe guides. If I had seen no more than what I saw before sunrise, I should have been willing to corroborate Mr. Pike's observation. But I was able to keep the phenomenon under observation for two hours, by the end of which time the explanation of the appearance had become clear. The visible parts that first looked like mock-suns were actually ends of segments of the primary circle in the neighborhoods of the mock-suns, as became evident when the whole phenomenon had risen with the mock-suns showing no higher than the sun. When the halo was first to be seen before sunrise, the horizon did not make a sheer edge

where it cut off the risen parts of the segments, but for half a degree or more the bank of haze at the horizon was dense enough to absorb the light of the halo, and the risen parts seemed to stand well up in the sky with a blank space between them and the horizon, and to be complete objects in the field of view. This was not really the case, but on account of the absorption of light they had the appearance of being complete mock-suns. Mr. Pike's own statement suggests why he failed to note the real facts of the case, for he says :—" The effects (of the sunrise were) of long duration, as the sun is close to the horizon a considerable time before he shows above it." The duration was evidently too long for the whole phenomenon to be visible as a single feature, or to be kept under observation by one person until it explained itself, as it can do to better advantage here in more southern atitudes where the sun rises more abruptly with reference to the horizon. The phenomenon on each occasion showed the great distance of the halo, whose light was so completely absorbed by the haze of the horizon.

Dr. Leslie G. Pearce, of Brantford, Ont., in a letter to Professor Chant, recorded the same halo as it appeared at that city, by means of a diagram. He adds this remark :—" On February 4th, at 7.30 a.m., we had a very fine display of solar halos. What we saw in Brantford was like the following sketch."



SOLAR HALO, FEBRUARY 4, 1918, OBSERVED AT BRANTFORD BY LESLIE G. PEARCE

It becomes evident from the diagram sent by Dr. Pearce, that at Brantford, just after sunrise there was absorption of the lower parts of the halo by the haze of the horizon, similar to the absorption phenomenon observable at Barrie.

A FEW NOTES ON AMATEUR OBSERVERS AND OBSERVATIONS

By W. F. Denning

THE contributions of Mr. A. R. Hassard and Dr. Leslie G. Pearce in recent numbers of this Journal must have proved entertaining to many, for it is always interesting to read of the difficulties and successes experienced by amateurs in the pursuit of their hobby.

Those whose initial attempts to survey the heavens were made with a 3-inch telescope and who afterwards became the possessors of larger instruments and employed them in more methodical work recall their preliminary efforts with great pleasure. True the first views they enjoyed of celestial objects and phenomena were far inferior to those obtained at a later period, but the former came as instructive novelties and as such made a more charming and realistic impression on the mind than the more conspicuous and expanded pictures in powerful appliances could possibly do.

Like nearly every other observer, I have used 3-inch telescopes a good deal, especially in about the years 1865 to 1867: but though it is astonishing how much a small instrument of this aperture will show, it is certainly not nearly large enough for effective astronomical work in several branches. It will delight a beginner with excellent views, but when a man has habituated himself to the use of much larger and more capable means he cannot go back to very small glasses with satisfaction. The faint images induce eye-straining to an extent which soon becomes intolerable, and details, which he had been accustomed to grasp without the slightest effort in a large instrument, appear uncertain, shadowy and evanescent.

I think a 10 or 12-inch reflector forms the most handy and

convenient telescope for all the ordinary purposes of an amateur. It will show, and show well, the great majority of the more interesting objects in the heavens. It is effective in the critical study of planetary markings. I have employed Calver's mirrors of 8¼ and 12½ inches and With's of 10¼ inches, and found no great difference in their comparative revelation of detail,—on a really good night the largest mirror had a slight advantage.

I have never had any practical experience with very large instruments and so cannot tell to what extent atmospheric disturbance, etc., affect their performance. More than a generation ago there was an animated discussion as to the relative merits of large and small telescopes in dealing with detail on bright planets, and I argued that, judging from published observations and drawings, the great instruments previously in use could be regarded as possessing very little, if any, superiority. The large telescopes quoted were Herschel's 4-ft., Rosse's 6-ft., Lassell's 4-ft., Melbourne 4-ft., Newall's 25-in. Cooke O.G., Washington 26-in. Clark O.G. and Princeton 23-in. O.G. But better instruments have undoubtedly been constructed in later years and there seems no reason to doubt that the great refractors of the present day are decidedly more effective in studies of planetary markings than smaller instruments. M. E. Antoniadi and the Rev. T. E. R. Phillips found the 33-inch O.G. at Meudon, Paris, exhibited more detail on Mars and Jupiter than moderate-sized reflectors with the performance of which they were perfectly familiar.

The statement was confidently made a few years ago that the amateur astronomer might be regarded as quite an unnecessary adjunct to astronomical progress. In fact the modern character of observation had altered so much, instruments had become so powerful, photographic and other aids to facilitate research were so effective and comprehensive that mere amateurs were to be considered henceforth as obsolete. Perhaps the assertion was not meant seriously. In any case it may be taken as certain that the amateur will never be "out of the running." So long as there remains a new comet to be found, a temporary or variable star

to be discovered, a new or old planetary feature to be investigated or other important work to be accomplished, he may be expected to take his share. He will always claim a proportion of the discoveries made. The routine character of the work of our large observatories is of very different character to that engaging the amateur. He is a sort of free-lance in astronomy, and his more or less vigilant examination and watching of the heavens must necessarily result in discoveries.

BRISTOL, ENGLAND.

THE TOTAL SOLAR ECLIPSE, JUNE 8, 1918

By R. M. Motherwell.

THE earth moves around the sun once a year and the moon moves around the earth once a month. The orbit of the moon cuts the ecliptic at an angle of 5° 9′, so that once a month the moon passes between the sun and the earth and once a month the earth is between the sun and moon. In the first case the sun and moon are in conjunction and we have the phase called *New Moon*; in the second case they are in opposition and we have *Full Moon*. If the moon's orbit were in the same plane as the ecliptic then there would be always a solar eclipse at conjunction and a lunar eclipse at opposition. As, however, the inclination is over 5° and the combined diameters of the sun and moon as seen from the earth are only about 1°, there can be a solar eclipse only when they are in conjunction near the intersection of the moon's orbit and the ecliptic, *i. e.*, near a node of the moon's orbit, and a lunar eclipse when they are in opposition near the nodes. When the conjunction occurs within 17° of a node there is a solar eclipse and when opposition occurs within 11° of a node there is a lunar eclipse. There are never less than two eclipses in a year, both solar, and never more than seven, four of the sun and three of the moon, or five of the sun and two of the moon.

The moon moves from conjunction with the sun to conjunction with the sun again in 29·53 days, called the synodical period of the moon, and the sun moves from one node back to the same node again in 346·62 days. Nineteen periods of 346·62 days equal 6585·78 days and 223 periods of 29·53 days equal 6585·32 days, so in 6585·32 days from the time of conjunction at a node there will be a conjunction when the sun is only 6585·78 − 6585·32 = ·46 days or 28 minutes of arc from the same node

again. Now since there is a solar eclipse if conjunction occurs within 17° of the node and since a conjunction is repeated in 6585·32 days within 28′ where it occurred before, then, if an eclipse occurs at conjunction it will occur again at conjunction 6585·32 days later. This period of 6585·32 days or 18 years, 10 days, 7 hours (or 11 days, 7 hours if there are only 4 leap years), called the Saros, is the time in which eclipse conditions nearly repeat themselves and it renders the prediction of eclipses a comparatively simple matter. During 6585·32 days the earth will have made 6585·32 revolutions so the eclipse will be visible about 115° further west on the earth's surface.

Since in lunar eclipses the moon, shining by reflected light, is cut off from the light source, the sun, the eclipse occurs at the same time and is of the same magnitude at all points where it is visible. Occurring exactly at new moon they give a valuable check on the length of the synodical month. Solar eclipses being caused by the moon coming between us and our source of light, the time and magnitude of the eclipse vary according to the position of the observer. At some points there is no eclipse, at some points it is partial, and along a comparatively narrow path it may be total, the width of this path being the diameter of the shadow cone cast by the moon at the point where it is cut by the earth. The moon's velocity (synodical) being 2120 miles per hour and the earth's rotation being only 1040 miles per hour the shadow moves at the rate of 1080 miles per hour if it cuts the earth at the equator, so the duration of totality is very short, never much more than 7 minutes at the equator. Should all the conditions for a solar eclipse be fulfilled except that the apex of the shadow cone cast by the moon does not reach the earth, then at no point is the eclipse total. Along a narrow path, however, the sun will appear as a ring of light with the dark body of the moon in the centre. Such an eclipse is called annular.

Though of short duration, total solar eclipses are very interesting to astronomers because of the opportunities given to study the upper strata and corona of the sun and to search for planets between the sun and moon.

Figure 1 shows the relative positions of the sun, moon, earth and moon's shadow at total eclipse. The black section indicates where the sun's light is completely cut off, that portion of the earth between *c* and *d* being in the path of total eclipse.

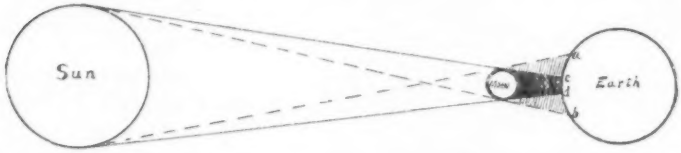


FIG. 1.—DIAGRAM ILLUSTRATING THE PRODUCTION OF A TOTAL ECLIPSE OF THE SUN.

The lighter shaded portions indicate the partial cutting off of the sun's light, *a* and *b* being the north and south limits respectively of the partial eclipse. In this figure we see that the apex of the shadow cone lies well within the earth.

Figure 2 shows the relative positions for an annular eclipse, the apex of the shadow cone being at *e* outside the earth's sur-

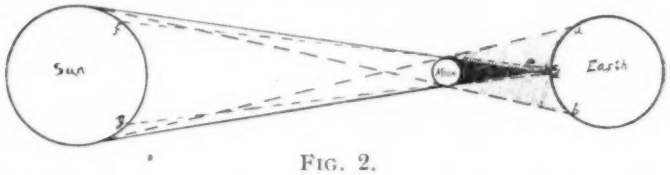


FIG. 2.

ILLUSTRATING THE PRODUCTION OF AN ANNULAR ECLIPSE.

face. The partial eclipse is visible within the limits *a b*, and *c* and *d* are the north and south limits of the path of the annular eclipse. A line drawn from *c* tangential to the moon cuts the sun's surface at *f* and similarly a line from *d* cuts it at *g*, so to observers between *c* and *d* the central part of the sun is hidden as shown in Figure 3. The moon and sun appear concentric to observers midway between *c* and *d*.

In the present year there are three eclipses, two of the sun and one of the moon. The lunar eclipse occurs on June 23-24 and is only partial. An annular eclipse of the sun occurs on

December 3, visible in South America. The most interesting one is the total solar eclipse of June 8. If we turn back the astronomical records to 1900 we find a total solar eclipse began

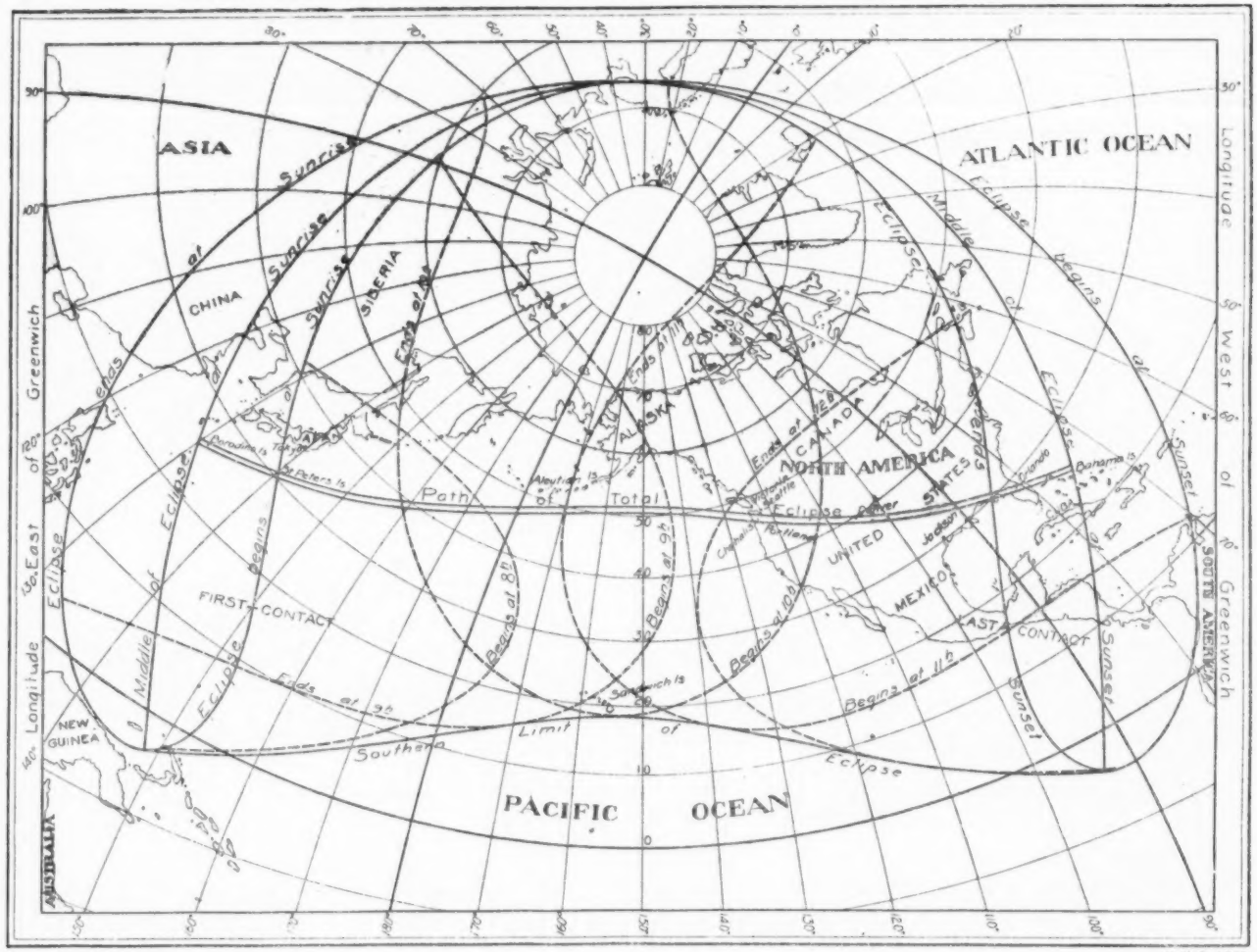
FIG. 3.—AN ANNULAR ECLIPSE OF THE SUN.

on May 28 at 0 hours (noon) at a point about 98° west of Greenwich. Add to this the saros, 18 years, 10 days, 7 hours, and we have 1918, June 3, at 7 hours, the time when the eclipse begins this year, *i. e.*, the time when the moon's shadow first touches the earth. Figure 4 shows that it also begins 150° east of Greenwich, about 112° further west than the eclipse of 1900 began.

The path of totality of the eclipse of 1900 began off the west coast of Mexico, passing across Mexico, the southeastern part of the United States, the Atlantic Ocean, Portugal, Spain and the northern coast of Africa, ending near the Red Sea. This year the path of totality begins south of Japan, crossing the Pacific Ocean and the United States, and ending east of the Bahama Islands. It is well situated for observation as it crosses the United States from the State of Washington to Florida, the largest city on the path of totality being Denver, Colorado. The greatest duration of totality in this eclipse is $2^m\ 23^s$ at a point in the Pacific Ocean south of Alaska. The greatest duration in the United States is at the Pacific Coast where it is slightly over two minutes. The width of the path of the shadow across the United States varies from 70 miles at the Pacific Coast to 58 miles at Denver and about 44 miles in Florida.

Figure 4 shows the paths of partial and total eclipse on June 8 of the present year over the earth's surface. The heavy curved lines at the left show where the partial eclipse begins at sunrise, is half over at sunrise and ends at sunrise. Those at the right

FIG. 4.—MAP OF TOTAL ECLIPSE OF SUN, JUNE 8, 1918. (From *Nautical Almanac*)



Note - The hours of beginning and ending are expressed in Greenwich Mean Time

U S O 1915

give the same phases for sunset. The heavy dotted lines mark the positions of the shadow of the moon on the earth's surface at the even hours and the heavy parallel lines extending from south of Japan to the Bahama Islands mark the portion of the earth's surface where the eclipse is total. The moon's penumbra or partial shadow first touches the earth at the point marked "first contact" at $7^h 29^m$ (G.M.T.) and the last point of contact as the shadow of the moon races off into space is at the point marked "last contact" at $12^h 46^m$ (G.M.T.).

At no point in Canada is the eclipse total, but it is visible as a partial eclipse in all parts of the Dominion ; in Prince Edward Island, Nova Scotia and Newfoundland, however, the sun sets before the eclipse ends. The times of beginning and ending, the position angles of the points of contact at beginning and ending, the times of maximum eclipse and the fraction of the sun's diameter covered at maximum eclipse for ten leading Canadian cities are given in Table I. The times are expressed in the standard mean time of each city in question, the method given in the *American Ephemeris* being used in all the computations. The left hand portion of Figure 5 shows the positions of the sun and moon at the beginning of the eclipse for each city, the dark side of the moon being towards us and so invisible ; the middle portion shows the appearance of the sun at maximum eclipse ; and the right hand, the positions of the sun and moon at the ending of the eclipse. The arrows indicate the direction of motion of the moon across the sun's surface, the position angles given in Table I. being measured from the north point of the sun toward the east.

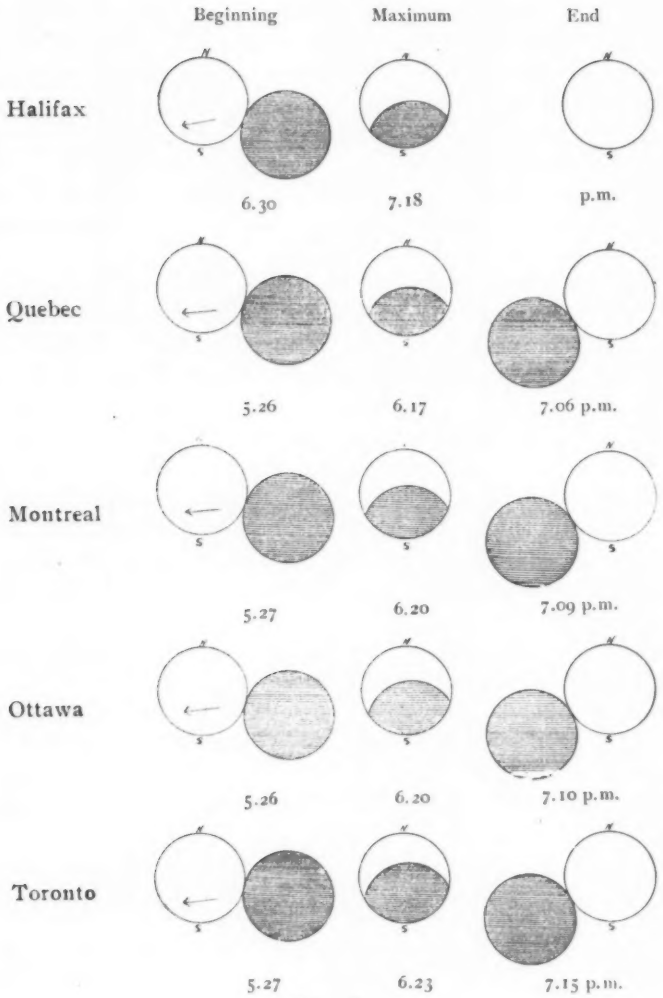


FIG. 5

APPEARANCE AT BEGINNING, MAXIMUM AND END OF ECLIPSE.

See Table I.

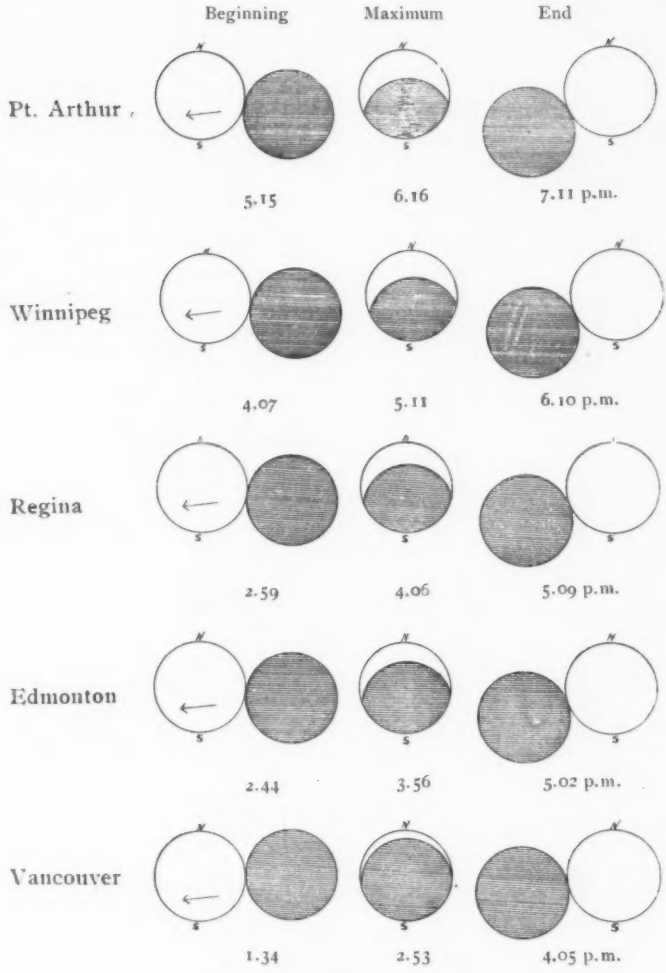


FIG. 5—(*Continued*)

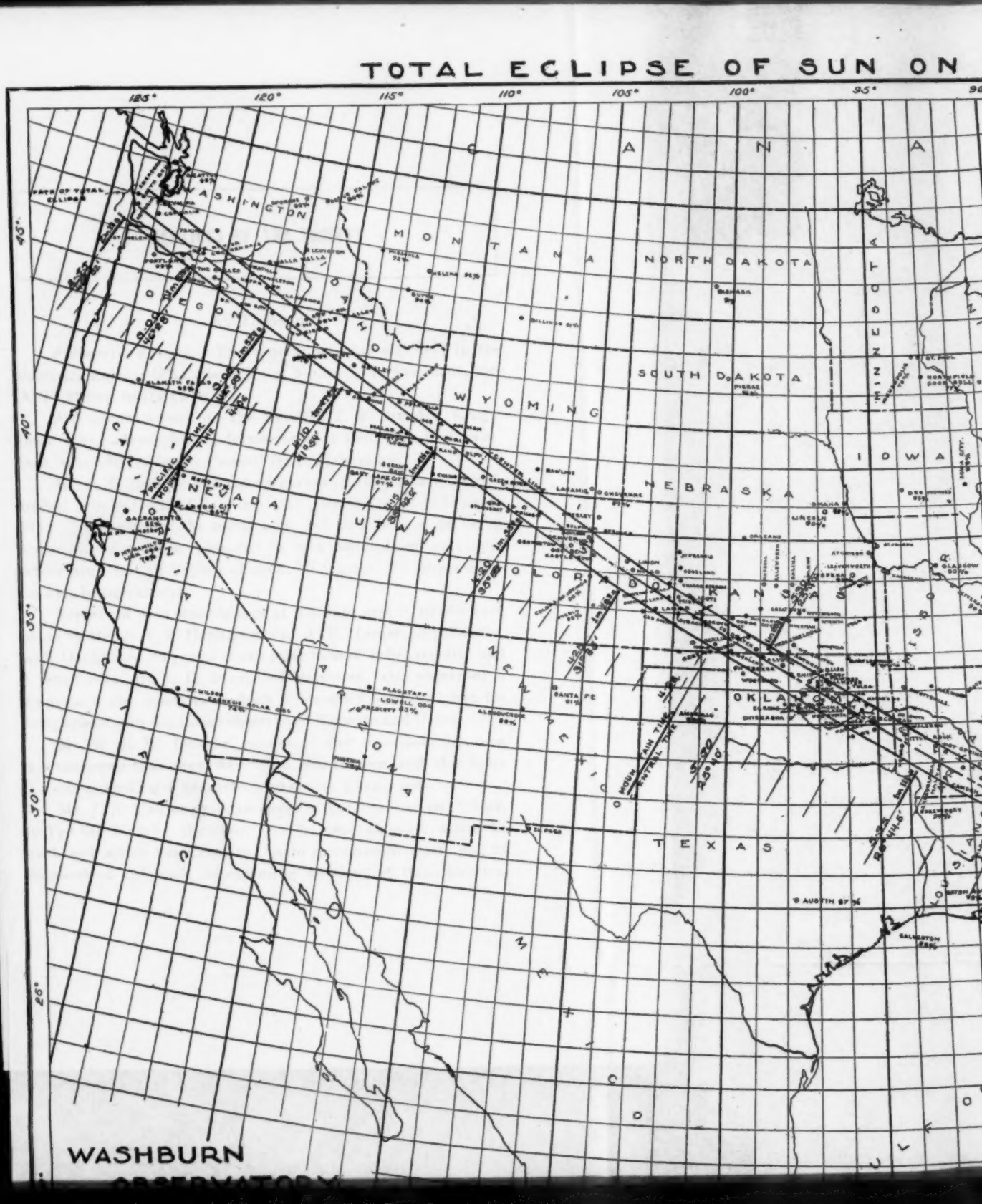
APPEARANCE AT BEGINNING, MAXIMUM AND END OF ECLIPSE.

See Table I.

TABLE I.

Place	Beginning		Maximum Eclipse	Ending		Mag. of Eclipse	Time of Sunset
	First Contact	Position Angle		Last Contact	Position Angle		
	h m s	°	h m s	h m s	°		h m
Halifax	6 29 46	248·4	7 17 56			0·52	7 55
Quebec	5 26 17	250·2	6 17 23	7 05 31	123·5	0·55	7 33
Montreal	5 26 50	253·0	6 19 36	7 09 01	121·2	0·59	7 42
Ottawa	5 26 14	254·4	6 20 20	7 10 27	120·1	0·61	7 51
Toronto	5 26 36	258·6	6 22 56	7 14 37	118·1	0·67	7 59
Pt. Arthur	5 15 25	257·9	6 15 32	7 11 10	116·5	0·67	8 54
Winnipeg	4 07 00	260·2	5 11 04	6 10 00	114·1	0·72	8 34
Regina	2 58 42	262·8	4 06 40	5 09 00	111·1	0·77	8 04
Edmonton	2 44 24	263·5	3 55 39	5 01 58	108·3	0·80	8 49
Vancouver	1 34 22	270·9	2 52 36	4 04 35	100·7	0·94	8 18

DOMINION OBSERVATORY,
OTTAWA, CANADA.


TOTAL ECLIPSE OF SUN ON
WASHBURN

N JUNE 8, 1918

90°
85°
80°
75°
70
65°
45°
40°
35°
30°
25°
NEW YORK
PENNSYLVANIA
OHIO
INDIANA
ILLINOIS
KENTUCKY
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
MISSISSIPPI
LOUISIANA
VERMONT
NEW HAMP.
MASS.
CONN.
PATH OF TOTAL ECLIPSE
DURATION
TIME P.M.
SUNS ALT.
CENTRAL TIME
EASTERN TIME
ECLIPSE AT SUNSET

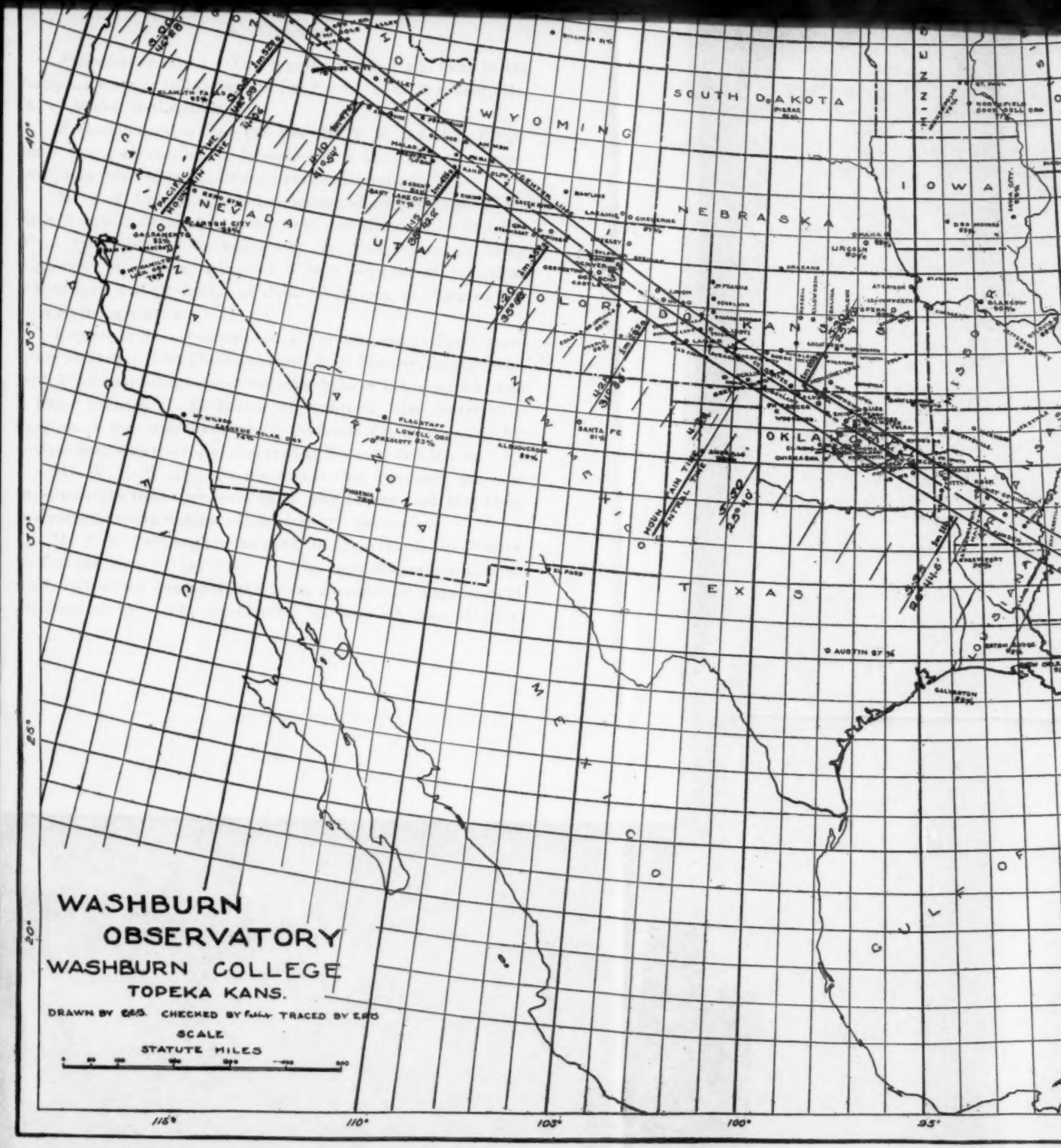


DIAGRAM SHOWING THE PATH OF THE MOON'S SHADOW ACROSS THE UNITED STATES, WITH THE STANDARD TIMES OF BEG

Reprinted from POPULAR ASTRONOMY, January, 1917.

Note:-Numerous cities are given with per cent of total eclipse

OF BEGINNING OF TOTALITY, THE DURATION OF TOTALITY AND ALTITUDE OF THE SUN

ary, 1917.

MEETINGS OF THE SOCIETY

At Toronto

February 12, 1918.—The regular meeting was held in the Society's Rooms, 198 College St., at 8 p.m. The President, Mr. A. F. Miller, in the chair.

A communication from the Rev. W. T. B. Crombie, Kingsbury, Que., advocating the formation of a Centre in that province, was referred to the Council for consideration.

Mr. J. R. Collins reported an aurora of elliptic form, which he had seen at Holland Landing, Ont., on the night of January 31st. It consisted of the usual arch, but this, instead of being a segment of a circle, appeared to be a segment of an ellipse whose apex had an altitude of about 60 degrees, the longer elliptic axis being vertical.

Reports of halo observations at Toronto and at Barrie were made by Messrs. J. P. Henderson and A. F. Hunter, respectively, with blackboard diagrams of the solar halo of February 4th; and a letter from Dr. L. G. Pearce, of Brantford, also contained a diagram of the same halo which Professor Chant sketched for comparison with the forms observed at Toronto and Barrie.

Mr. W. E. W. Jackson mentioned that sun-spots are now less numerous than they were some months ago, and that there is a corresponding diminution in magnetic phenomena.

Mr. J. R. Collins gave the paper of the evening on "How to Tell the Time by the Stars." The card diagram which he used, and which contained the main circumpolar stars, had 24 divisions of 15° each, representing an hour of time, identical

with the lines of Right Ascension. Polaris being near the centre of the disc, which was also the clock face by which the time of night can be learned. The line used as a base for the divisions is the equinoctial colure; this line through Polaris to β Cassiopeia is vertical at midnight for Toronto on September 24, and moves further west 4 minutes every night. This position being known for one night it can be readily estimated for any night during the year. A divided circle with a movable hand determines more accurately the position of the colure at any time. Some lantern diagrams further illustrated the subject.

February 26.—The regular meeting was held in the Society's Rooms, 198 College St. The President, Mr. A. F. Miller, in the chair.

A summary of the business transacted at the meeting of the Council on February 22nd was announced, *viz.*— That the Society would send Dr. Otto Klotz and Professor C. A. Chant to Colorado or some adjacent part to observe the Total Solar Eclipse on June 8th next; that Mr. C. P. Sparling had tendered his resignation as Treasurer after a period of service lasting for about ten years, and that the Council had accepted it with regret, had returned their cordial thanks for his valuable services, and had selected Mr. Stuart Strathy as Treasurer; that the vacancy on the Council made by Mr. Strathy's appointment as Treasurer had been filled by the election of Mr. Wm. Bruce, J.P., of Hamilton; that the letter of Rev. W. T. B. Crombie, of Kingsbury, Que., had received the Council's attention and the formation of a divisional Centre of the Society in Montreal will be encouraged and assisted; and that definite steps were taken to assist two divisional Centres where local efforts had languished on account of the war.

The following were elected members of the Society:—

Herbert G. Paull, 395 College St., Toronto.

Sgt.-Major W. A. Smelser, B.A.Sc., Hart House, Toronto.

Sergt. H. A. Mumford, 62 Gothic Avenue, Toronto.

Sergt. F. C. Darch, 70 Lyndhurst Avenue, Toronto.

David A. Keys, M.A., 87 Avenue Road, Toronto.
Dr. Fred. N. Badgley, 110 Avenue Road, Toronto.

Mr. A. F. Miller reported that on the previous night (February 25) at midnight the barometer at Toronto had reached a lower point than it had attained for a long time, his instrument showing 28·34 inches; on the previous Thursday there had been a high barometer, and the wide difference between the two dates would result in a difference of pressure on a human body of normal size of three tons and 800 lbs.

Professor Chant reported that Dr. Satterly had also recorded a minimum reading of the barometer of 715 mm. at 10 p.m. on February 25th.

A. F. Hunter reported having observed an artificial aurora at Barrie, at 5.30 a.m. on February 17, made by the electric lighting system of the town while the air was full of fine crystals of frost.

J. W. Campbell, Ph.D., gave the lecture for the evening on "Deviations of Falling Bodies." He pointed out that it has been well established for a long time that a falling body will deviate from the plumb line toward the east owing to the rotation of the earth. There is still some question as to whether the falling body has also a meridianal deviation, that is—in a north or south direction. Several men have experimented to find if there is southerly deviation.

Nearly all have obtained results showing southerly deviation, but differing by various amounts. In fact the actual deviation is necessarily different for different parts of the earth. Gauss and Laplace started the analytical solution of the problem in 1803, but they disagreed as to the results. Gauss found there was an equator-ward deviation, but Laplace, also from mathematical analysis, found no deviation. From similar analyses, R. S. Woodward, in 1913, found a pole-ward deviation, but three other authorities, working on the problem in recent years, got equator-ward deviations. The analytical method consists in solving differential equations to give the path along which the body will fall. R. S. Woodwood made the same assumptions of the values

of terms employed as Professor Moulton, of Chicago, made, but solved the equations in a way which Professor Roever showed to be erroneous. Professor Roever published his results in 1911 and 1912 in the *Transactions* of the American Mathematical Society, and R. S. Woodward, in 1913, published his in the *Astronomical Journal*. The lecturer concluded by giving a simple explanation with a cone, showing why bodies deviate toward the equator instead of the pole.

Professor Chant pointed out that in shooting at long range gunners have to take into account the rules of deviation and point their cannons accordingly. He also mentioned that in the Washington Monument at Washington D.C., which is such a good place for experiments on this problem, having a height of 555 ft., the actual deviation of the falling body was only one inch, so that the quantity was a very small fraction. The equatorward motion is due to the rotation of the earth.

Several other members took part in the discussion, from which it became evident that the experimental results had usually been obtained from using the shafts of deep coal mines.

A. F. HUNTER,
Recorder.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

February, 1918

Temperature.—The temperature was above the average from the Rocky Mountains to the western shores of Lake Superior, and below the average elsewhere over the Dominion. The positive departures varied from 1° to 3·5°, and the negative from 1° to 6°.

Precipitation.—The precipitation was everywhere above the average amount except at a few points in the interior of British Columbia, and over the larger portions of Alberta, Saskatchewan and Manitoba, where there was a very slight deficit. The chief positive departure occurred in Southern and Eastern Ontario and in Southern New Brunswick, and over Nova Scotia, and varied from one to one and three-quarter inches.

Depth of Snow on the Ground at the Close of the Month.—In Northern British Columbia snow covered the ground to a depth of over 40 inches. In the Western Provinces the covering was from 3 to 4 inches in southern localities, and from 12 to 30 inches in the northern parts. In Ontario from 30 to 40 inches in northern and eastern regions, and from 6 to 8 inches in the extreme southern districts. In Quebec from 14 to 48 inches, and in the Maritime Provinces from a trace along the south coasts to over 36 inches in the northern parts.

Temperature for February, 1918

Station	February		Station	February	
	Highest	Lowest		Highest	Lowest
Yukon			Kenora	38	-34
Dawson	2	-50	Kinmount	42	-30
British Columbia			Kingston	42	-26
Atlin			Kitchener	46	-22
Agassiz	51	19	London	50	-21
Barkerville	36	-20	Lucknow	44	-34
Kamloops	53	- 2	Markdale	46	-31
New Westminster	49	18	North Gower	48	-30
Prince Rupert	50	14	Oshawa	42	-12
Vancouver	50	20	Ottawa	43	-26
Victoria	52	25	Paris	46	-20
Western Provinces			Parry Sound	42	-37
Battleford	42	-42	Peterboro'	46	-39
Calgary	54	-28	Port Arthur	44	-26
Edmonton	53	-33	Port Burwell	49	-19
Medicine Hat	46	-44	Port Dover	45	-22
Minnedosa	36	-38	Port Stanley	45	-23
Moose Jaw	43	-32	Queensborough	44	-30
Oakbank	40	-34	Ronville	43	-38
Portage la Prairie	37	-32	Southampton	43	-28
Prince Albert	44	-46	Sundridge		
Qu'Appelle	41	-38	Stonecliffe	42	-32
Regina	37	-38	Stony Creek	52	-20
Saskatoon	41	-40	Toronto	49	-20
Souris	42	-35	Uxbridge	44	-27
Swift Current	44	-34	Wallaceburg	57	-22
Winnipeg	41	-30	Welland	49	-19
Ontario			White River	35	-51
Agincourt	47	-24	*Quebec*		
Aurora	45	-27	Brome	45	-28
Bancroft	42	-32	Father Point	42	-24
Barrie			Montreal	42	-24
Beatrice	43	-35	Quebec	44	-27
Bloomfield	43	-26	Sherbrooke	50	-25
Brantford	52	-22			
Chapleau	46	-37	*Maritime Provinces*		
Chatham	55	-16	Charlottetown	40	-10
Clinton	46	-26	Chatham	46	-24
Collingwood			Dalhousie		
Cottam	57	-22	Fredericton	46	-26
Georgetown	46	-29	Halifax	48	-10
Goderich			Moncton	47	-23
Gravenhurst	44	-34	St. John	48	-14
Grimsby	51	-21	Sussex	49	-29
Guelph	46	-25	Sydney	48	-12
Haliburton	43	-37	Yarmouth	48	- 2
Huntsville	49	-37			

MAGNETIC OBSERVATIONS

JANUARY, 1918

The month of January was particularly free from any strong magnetic disturbances and only on the 2nd, 12th, 13th, 30th and 31st were moderate disturbances recorded. Numerous groups of small sunspots were visible during the month both north and south of the sun's equator.

AGINCOURT MAGNETIC OBSERVATIONS

Lat. 43° 47′ N.; Long. 79° 16′ W.

January, 1918		D. West	H	Z	I
		° ′	γ	γ	° ′
	Mean of Month	6 38·1	15942	58425	74 44·3
	Maximum	6 57·9	15988	58548	
	Date of Maximum	30	2	30	
	Minimum	6 11·8	15850	58364	
	Date of Minimum	30	31	30	
	Monthly Range	0 46·1	138	184	
Mean Daily Amplitude	From hourly readings	7·2	38	9	
	From means of extremes	19·2	74	19	

MEANOOK MAGNETIC OBSERVATIONS

Lat. 54° 37′ N.; Long. 113° 21′ W.

January, 1918		D. East	H	Z	I
		° ′	γ	γ	° ′
	Mean of Month	27 47·3	12937	60431	77 55·0
	Maximum	29 07·1			
	Date	30			
	Minimum	27 14·5			
	Date	30			
	Monthly Range	1 52·6			
Mean Daily Amplitude	From hourly readings	6·3			
	From means of extremes	27·6			

H and Z are given in Gammas. (1 γ = 0·00001 C.G.S.).

All results are reduced to International Magnetic Standard.

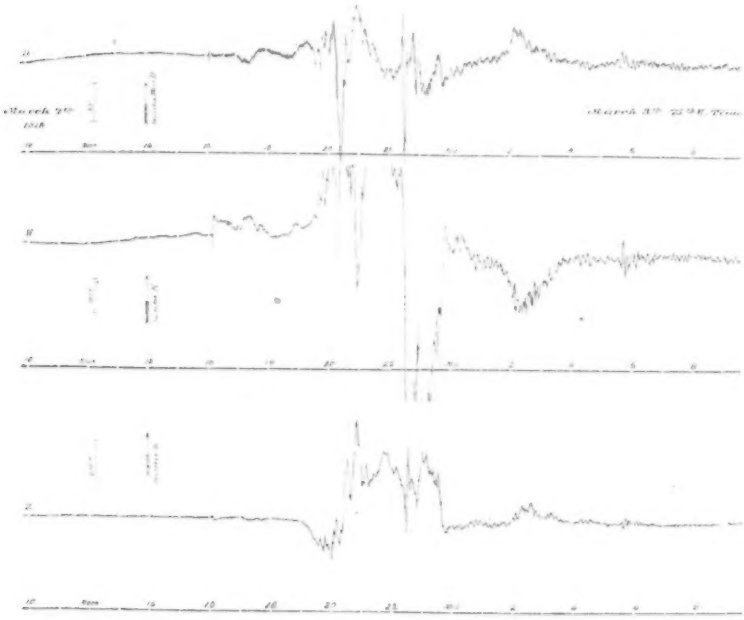
The value for I at Meanook is the mean of all the observations made during the month without regard to the time of day.

The value of H at Meanook is the mean of two observations made about the middle of the month, and the Z is obtained by the formula Z = H tan I.

W. E. W. J.

THE MAGNETIC STORM OF MARCH 7 AND 8, 1918.

The Agincourt record of this storm indicates a very abrupt beginning at 16 h. 6.9 m. 75th M.T., March 7, in all three elements. The magnitude of the first movements was exceptionally large. The West Declination increased 6′.4, followed immediately by an easterly swing of 14′.1; the Horizontal Force decreased 48 γ, followed immediately by an increase of 113 γ; and the Vertical Force decreased 6 γ, followed by an increase of 17 γ. The disturbance, as shown in the tracings reproduced, herewith had its greatest



PHOTOGRAPHIC RECORD AT AGINCOURT OF THE MAGNETIC STORM, MARCH 7 AND 8, 1918.

(The highest is the Declination, the middle the Horizontal Force and the lowest the Vertical Force).

effect on the magnets from about 18 h. 30 m. to 24 h. The large swings in *D* at 20 h. 30 m. and 22 h. 30 m. had amplitudes of 1°51′ and 1°58′ respectively. From 18 h. 30 m. to 22 h. 20 m. *H* was much above normal and passed frequently above the limit of the recording apparatus. A very rapid fall in *H* began at 22 h. 20 m. and at 22 h. 30 m. passed below the lower limit of the recording apparatus. The upper and lower limits are respectively 0.16157 and 0.15461. The Vertical Force was above normal from 19 hours to 20 h. 25 m., with a maximum departure of +149 γ. At 20 h. 25 m. it began to fall rapidly and reached a minimum of 358 γ below normal at 20 h. 53 m. In all three elements the forces became about normal at near 24 hours, but during all morning of the 8th, sharp serrations continued to be recorded.

The base line values are for *D* 5° 24′.8 West, for *H* 0.15557 and for *Z* 0.58733.

At the time of the disturbance there was a fine auroral display seen in many parts of the country, and reported also in Europe. Mr. H. B. Collier, of Viking, Alberta, sends the following note:—

The whole southern sky at 8 p.m. (March 7), assumed a pale greenish hue, while the northern sky was clear and remained almost clear during the three-hour demonstration. Bands of greenish white shot up from the horizon on the east and west and met in the zenith, where they were joined by many points apparently emanating from the north, but having no visibility across the northern sky. The persistency with which the light in various forms of shafts and curtains, held to a path across the sky, east and west, within bounds of not more than 30 degrees, is remarkable. Practically all the sky south of this path remained a pale green color, while the sky north was perfectly clear, with the exception of an occasional small patch of auroral light.

At several periods of the demonstration, great patches of red formed a background to the play of the bright shafts. I saw no red bands or shafts at any time. The deep coloring was always as a cloud showing vividly in the rear of the greenish white display.

Earthquake Records by the Milne Seismograph

TORONTO

Sir Frederic Stupart, Director.

P. T. = Preliminary Tremors. S. = Secondary Waves. L.W. = Large Waves. A.C. = Air Currents. Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1918	P. T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm	
1812	Feb. 3			14 58·8 15 00·9	15 05·0	15 31·0?	1·3	Marked gradual thickening.
1813	" 6			3 59·2 4 09·5	4 12·0	4 33·0?	0·4	Gradual thickening.
1814	" 7			5 42·5 5 58·8	6 40·2	A.C.	0·4	
1815	" 12			1 34·0? 1 41·3		A.C.	0·1	
1816	" 12			19 33·7		19 40·6	0·05	
1817	" 12			20 20·7	20 23·5	20 29·6	0·3	
1818	" 13			3 53·4 4 00·0	4 18·6	4 24·5	0·2	
1819	" 13			6 44·9 7 00·1	7 14·8	8 52 4?	2·9	*Amoy, China. [doubtful markings at 6h 21m.2 [and 6h 32m.6.
1820	" 18			16 58·3		17 06·6	0·1	
1821	" 19			17 21·0 17 26·1	17 30·2	17 47·3?	0·8	Marked gradual thickening.
1822	" 20			6 54·7	6 56·2	6 59·3?	0·3	Grad. thickening
1823	" 23			19 02·7	19 05·3	19 14·6	0·2	
1824	" 24			23 14·5 23 17·5	23 20.5	23 34·3	0·3	
1825	" 25			7 03·2	7 06·2	7 15·2	0·3	
1826	" 27			4 16·5 4 20·8			0·05	

*Special despatches state that nearly 10,000 persons lost their lives and the Chinese city of Swatow was practically destroyed as a result of this earthquake.

Boom period 18 seconds. Pillar inclination 1mm. = 0″·45.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1918	P.T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m s	h m s	h m s	h m s	h m s	mm	
1822	Feb. 3	14 45 36?		14 51 30	14 55 26	15 18 13?	0·4	
1823	" 4				20 40 16?		0·05	Near Revelstoke
1824	" 6			4 04 22			0·05	
1825	" 7	5 35 22?		5 44 13	5 47 49	6 54 32	0·5	4230 km.?
1826	" 12			19 30 30			0·05	
1827	" 12	20 08 38?		20 12 34?	20 15 05	20 21 31	0·2	
1828	" 13	*		3 55 24			0·2	Trace indistinct
1829	" 13	6 31 10	6 39 32	6 46 36	6 59 42	8 10 02	1·5	6860 km. Trace rather indistinct
	" 13	*						
1830	" 19			17 05 38?	17 14 38	17 37 08	0·4	Marked gradual thickening.
1831	" 27			4 07 07			Less than 0·05	

*Local tremor lasting about 1 second reported in several parts of the city, felt at 13 hours G.M.T. Not recorded.

Boom period 18 seconds. Pillar inclination 1mm. = 0″·54

VERTICAL SEISMOGRAPH

Date 1918	P.T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
	h m s	h m s	h m s	h m s	h m s	μ*	
Feb. 4	20 39 46		20 40 46	20 40 52	20 43 28	16	550 km. near
" 7				6 06 00		2	Revelstoke.
" 13				7 07 00		7	*True earth movement.

J. Y.

ASTRONOMICAL NOTES

SCIENCE IN EDUCATION.—I wish to call attention to a point in the discussion which has been continued through the past year on the vital question of the position of Science in Education. The need for a greater appreciation of the value of science has been brought into such prominence by the war that most of those who have advocated the claims of science in education have not, unnaturally, laid the greatest stress on the importance of science to the welfare, the power, and even the safety, of the nation. The supporters of literary studies have, on the other hand, dwelt mainly on the fact that literature broadens a man's horizon, and gives him new interests and pleasures, that it teaches him how to live, if not how to make a living. The result of this divergence of appeal has made the discussion appear, to those who watch it from outside, almost like a discussion between Spirituality and Materialism, or between a saint and a man of business. Echoes of this sentiment are to be found in the opinions expressed by some members of the Labor Party ; there is a tendency to regard science teaching with suspicion, as being intended to make the working man more valuable to his employer rather than to increase the brightness and interest of his own life.

I recognise — and I know no man of science who does not —the necessity of literary study as a part of the education of every boy and girl, but I must protest against the idea that literature has a monopoly in the mental development of the individual. The study of science widens the horizon of his intellectual activities, and helps him to appreciate the beauty and mystery

which surround him. It opens up avenues of constant appeal to his intellect, to his imagination, to his spirit of inquiry, to his love for truth. So far from being entirely utilitarian, it offers romance and interest to things which to those ignorant of science make no appeal to the intellect or imagination, but are regarded by them from an exclusively utilitarian point of view. A knowledge of science brightens and widens the intellectual life, and is a constant stimulus to the intellect and imagination.—SIR J. J. THOMSON, Presidential Address, *Proceedings Royal Society*, London, March 1, 1918.

RELATIVITY AND GRAVITATION.—A pamphlet has just reached us entitled "La spostamento del perielio di mercurio, e la deviazione dei raggi luminosi, secondo la teoria di Einstein," by Attilio Palatini (from *Nuovo Cimento*, July, 1917; Pisa: Stabilimento Tipografico Toscano). The pamphlet, like the article by Professor Eddington, in *Nature*, of December 28, 1916, (Vol. XCVIII., p. 328), aims at making the outlines of Einstein's relativity theory clear to those who have not access to his original works. The points in which the new theory differs from our earlier conceptions of Euclidean space and Newtonian dynamics are clearly brought out. As the title indicates, particular stress is laid upon the manner in which it completely accounts for the access of 43″ per century in the motion of the perihelion of Mercury's orbit, which had been recognised as a difficulty in the Newtonian theory. It is especially noteworthy that the Einstein theory was laid down quite independently of this result, which is, therefore, in the nature of an undesigned coincidence. It differs in this respect from some other relativity theories, which have assumed arbitrary values for certain co-efficients, in order to satisfy the observed facts. Einstein's result involves no arbitrary constant, but simply depends on the ratio of Mercury's velocity to that of light. The pamphlet employs two different methods of development, each leading to the result that the perihelion advances 0″·1 in one revolution of Mercury.

The other test proposed by Einstein for his theory is that a

ray of light from a star just grazing the sun's surface and passing on to the earth would be deflected through an angle of 1″·75. It is shown in the pamphlet how this result is deducible from Einstein's principles, and illusion is made to total solar eclipses as affording opportunities for a practical test. The Astronomer Royal has already urged that advantage be taken of the very favorable total eclipse of May, 1919, for experiments of this kind. Professor Eddington has pointed out that the doctrine that light has inertia would lead us to expect a deflection of 0″·88 at the sun's limb in any case; so the Einstein test depends on the difference between this value and 1″·75.—*Nature*, February 21, 1918.

The Location of the Sun's Magnetic Axis.—The discovery by Mr. Hale in 1913 of a general magnetic field surrounding the sun raised at once questions of great interest. First among these was the character of the field and the variation of its intensity over the solar surface. A preliminary investigation showed that approximately the sun may be regarded as a uniformly magnetized sphere, its axis coinciding with the axis of rotation. The minuteness of the observed quantities and the difficulties experienced in their measurement necessitated the provisional acceptance of this simple hypothesis; nevertheless, well-known peculiarities of the earth's magnetic field suggested that the solar field might deviate from that of a spherical magnet, and that its axis might be inclined to the rotation axis by an amount susceptible of measurement by special series of observations. This communication is concerned with the latter of these questions, namely, the position of the magnetic axis.

Observations of the sun's field are made by placing the slit of the spectrograph in coincidence with the central solar meridian.

The original investigation by Mr. Hale was based on only four lines. Later observations have increased the number known to be affected by the sun's field to 30, for 18 of which results were communicated at the Atlanta meeting of the American Astronomical Society in December, 1913. For the investigation here de-

scribed three chromium lines, λλ 5247, 5300, 5329 were selected, which are of special suitability for measurement because of intensity, location in the spectrum, and magnitude of displacement.

From June 8 to September 23, 1914, these lines were photographed daily under the direction of Ellerman, with almost no break in the series. The circumstances were most favorable owing to the small number of sun-spots, whose magnetic fields, many times the intensity of the underlying field of the sun, seriously complicate the investigation. Because of advantages connected with the numerical solution and the necessity of limiting what at best could be only a very laborious undertaking, the observations were confined to the zone 45° N–45°S. Twelve spectrograms with exposures of 10 to 30 minutes constituted the normal observing program for each day. For 63 of the days the photographs have been completely measured by van Maanen, who has assumed the responsibility for this part of the undertaking. More than 2000 sets of measures were required, each involving about a hundred settings of the micrometer.

The result for P is of much interest in relation to the rotation period of the sun. For the reversing layer this ranges from 26·4 days (synodic period) at the equator to about 30·5 days at 45°, the value for P* not being equalled until approximately 55° is reached. Hence for latitudes lower than this limit, the magnetic axis in its motion about the axis of rotation appears to lag behind the reversing layer. The bearing of this circumstance upon the physical constitution of the sun must await further elucidation. In the meantime, however, it should be noted that P may not be constant. The present series of measures, at any rate, is insufficient to establish its freedom from fluctuations; and none of the earlier observations, which were made with other purposes in view, are adapted to the investigation.—Seares, van Maanen, and Ellerman, of Mount Wilson Solar Observatory, *Proceedings National Academy of Sciences*, Washington, January, 1918.

P = The period of rotations of the magnetic axis about the physical axis of rotations.

THE DIURNAL CHANGES OF THE EARTH'S MAGNETISM. The diurnal magnetic variations are of two distinct types having periods equal respectively to the solar and lunar days. The solar diurnal variations are readily observable — the variation in declination, for instance, may exceed ten minutes of arc in summer at Greenwich. The changes affect the magnetic force mainly in the horizontal plane, the mean daily range at Greenwich sometimes approaching $\frac{1}{3}$ per cent. of the whole horizontal force. These changes completely mask the lunar diurnal magnetic variations, which are not more than one-tenth as great. The determination of the latter requires the careful reduction of a large number of hourly values of the magnetic elements (*i. e.*, components of force, such as north, west, and vertical), the solar diurnal changes being first abstracted.

The solar changes vary in magnitude and type with the *latitude* of the station, but not to any great extent (between latitudes 60° north and south) with *longitude*, approximately the same changes taking place, at corresponding *local* times, at all stations along any circle of latitude. Thus we may imagine the changes to be due to a "variation" field of magnetic force (superposed on the main normal field) which remains constant in position relative to the sun, while the earth revolves within it. The variation field changes with the seasons, the daily range being much larger at midsummer than in midwinter (*e.g.*, at Greenwich the mean range in declination in July exceeds twice that in January). Also its magnitude at times of great solar activity exceeds that at sunspot minimum by an amount of the order of 100 per cent. At all epochs in the solar cycle, moreover, the mean diurnal variation is found to be greater on magnetically "disturbed" than on magnetically "quiet" days. Finally, at all times and in all elemenst the diurnal inequality (in the mean of a number of days sufficient to average out irregular disturbances) is such that the changes are mainly confined to the hours of daylight; the duration of darkness varies with the season, of course, but the night hours are always, as regards the average daily changes, magnetically quiet.

These characteristics clearly indicate a very intimate relation between the magnetic variations and *solar radiation*—for it is easy to show that the former cannot be produced by any probable direct magnetic action of the sun. In the circumstances, it is most natural to regard the magnetic variations as consequences of some electro-magnetic action which is influenced by solar radiation, and occurs mainly in the sunlit atmosphere. There is much significance in the *sensitiveness* of the magnetie variations to changes in the solar radiation received, both throughout the day and night, the year, and the solar cycle ; no phenomena which occur in the lower atmospheric strata, or within the earth, are known to exhibit all these characteristics. It seems probable, therefore, that the solar radiations which are effective in the present connection never penetrate to the lower regions of the atmosphere : they are absorbed in the upper strata, and there produce the magnetic variations. These conjectures are borne out by mathematical analysis of the diurnal magnetic variations. It is found that the variation field can be represented fairly completely by a simple "potential" functions, which indicate that the field is due to electric currents, principally situated above the earth's surface. A definite proportion (about two-fifths of the whole) is, however, produced by currents flowing within the earth.

Viewed from the physical standpoint, the circumstance recalls the fact that the solar diurnal magnetic changes are mainly confined to the daylight hours ; in this connection the dependence of the solar variations on local time was referred to the existence of a solar diurnal variation field of magnetic force which remains constant in its relation to the sun during the earth's rotation, and is of greater amplitude over the sunlit than over the dark hemisphere. The facts regarding the lunar variation suggest a similar but more complex conclusion. The lunar diurnal variation is attributable to a field of force which remains constant in orientation relative to the moon, during the earth's rotation ; but it is of greater amplitude over the sunlit than over the dark hemisphere, so that the character of the variatian field

with respect to the moon varies according to its angular separation from the sun (*i. e.*, according to the lunar phase).

The above discussion indicates that the daily magnetic variations, besides offering in themselves an interesting subject of investigation, afford information which would otherwise be difficult to obtain, concerning inaccessible regions above and beneath the earth's surface. The results so to be derived are by no means confined to those which have been mentioned here, and many points remain to be dealt with by further research. Among these are the seasonal changes of the daily magnetic variations, which have not yet been adequately accounted for; and also the height and vertical thickness of the atmospheric strata in which the electric currents flow. Probably they do not lie *below* the lower level of the auroral layer, which in high latitudes has been found by Störmer to be about 100 km. high. The level may be different, however, in different latitudes. Again, the nature of the solar ionizing radiation is still obscure. Finally, it should be remarked that in high latitudes (*e.g.*, beyond 60°), the daily magnetic variations present special features which have, as yet, been but little studied.—S. CHAPMAN, *The Observatory*, No. 522.

A STUDY OF MARS.—The Mandeville Station in Jamaica has continued under the direction of Professor W. H. Pickering. A special study was made of Mars from which he concludes that the dark areas are changing their positions annually back and forth by a few hundred miles, sometimes carrying the so-called canals with them; that these areas gradually turned green and later brown. Temporary blue areas were detected near the polar cap. The color determinations were made with a tungsten lamp shining through blue glass. The measured breadth of the canals ranged from 30 to 110 miles. The duplication was detected, and attributed to the rapid passage of waves of irregular density in our own atmosphere. The colors of all the planets have been determined and those of the fixed stars begun. The changes in the snow areas on the moon have been studied and also the elliptical forms of Jupiter's satellites.—"Annual Report," Harvard College Observatory, 1916. J. R. C.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

NOT A TRANS-NEPTUNIAN PLANET.

The object discovered by Wolf and referred to on page 127 of our last issue, has been definitely shown to be an asteroid, not a trans-Neptunian planet as was conjectured. The observation of a satellite to the body has not been confirmed, and the period is not nearly so great as assigned in the elements which were quoted.

From observations on February 5, 12 and 19, Messrs. Jeffers and Mundt, of Berkeley, Cal., have computed the following elements, which appear in Harvard *Bulletin*, No. 655, dated March 11:—

ELEMENTS

Time of perihelion passage	(T)	1918, January 3·96 G.M.T.
Perihelion minus node	(ω)	348° 13′
Longitude of node	(Ω)	110° 41′
Inclination	(i)	9° 7′
Perihelion distance	(q)	1·189
Eccentricity	(e)	0·5526
Periodic Time	(P)	4·33 years

It is stated that there is some uncertainty, however, due to inconsistent observations.

NOVA MONOCEROTIS AND NOVA PERSEI.

From Copenhagen is cabled the news that on February 4, Wolf, of Heidelberg, photographed a star with a spectrum of a

nova, and having a magnitude 8.5. Its position is R.A. 7 h 21.9m., Dec.—6° 29′ (1900).

From photographs taken at Harvard Observatory, the following information is obtained:—

December 22, 1917,	not seen, fainter than 9·8 mag.
January 1, 1918,	5·4 mag.
February 4,	8·9 "
February 17,	9·0 "

It is also found on intermediate dates.

As to its spectrum, Director Campbell telegraphs: "Spectrum by Moore and Paddock has reached nebular stage, consisting of extremely broad, bright bands of hydrogen, nebulium; moderately strong absorption near centres of green bands."

On photographs taken at Harvard Observatory on February 21 with the 24-inch reflector, Miss Cannon finds

Lines:	Hζ,	Hε,	Hδ,	Hγ	and	4363,	4520,	4686,	Hβ,	5007,	5440,	5630,
Intensities:	2	2	5	10			1	4	1	3	1	3
	5750,	Hα										
	1	15										

This is the first bright nova since Enebo's Nova Geminorum, 1912.

Various observations of Anderson's great nova in Perseus (1901), have been recently made and are given in recent Harvard *Bulletins*.

On photographs taken between August 16 and 28, 1917, Belopolsky (of Pulkowa) found that the nova had increased from 13 to 11.5 mag.

At Harvard, three plates taken in March, 1914, gave mag. 13.02. Two photographs taken on September 5, 1917, gave a mag. 13.4, while a plate taken on August 17, 1917, does not show the nova, though stars of mag. 12.2 are recorded.

Observations at the Yerkes Observatory shows that the nova became very faint in the early part of the winter of 1916, and then brightened up in the latter part of that winter. In the middle of August, 1917, it was again faint, and then increased over one mag.

nitude. Barnard gives the following magnitudes made visually with the 40-inch telescope:—

MAGNITUDES OF NOVA PERSEI

	C.S.T.			Mag.		C.S.T.			Mag.
	d	h	m			d	h	m	
1916, January	5	7	35	12·4	1917, February	10	11	0	12·7
December	9	9	0	13·8		20	6	45	12·6
	16	11	30	13·0	August	18	14	0	12·9
	21	8	0	13·1		25	13	0	12·5
	27	7	0	12·9		29	15	0	11·9
	30	13	20	13·3		30	13	30	11·6
1917, January	23	9	10	12 0	September	5	13	35	12·1

With these may be compared the following observations, communicated by Dr. A. van Maanen, of the Mt. Wilson Observatory:

1915, August	31,	12·4		1916, January	12,	12·7
September	2,	12·4		December	18,	13·8
September	30,	12·5		1917, September	14,	12·8
1916, January	11,	12·6				

Spectroscopic observations on the star were made by Dr. W. S. Adams and Mr. F. G. Pease, of the Mt. Wilson Observatory. They obtained a photograph of the spectrum with a low dispersion spectrograph and the 60-inch reflector on the night of September 26, 1917. "The spectrum shows no variation that we can detect from that observed in November, 1913. It is of the Wolf-Rayet type, with strong, bright hydrogen lines and λ 4686."

MORE "PILLARS OF LIGHT."

Mr. H. S. McClung, of Regina, writes as follows:—

Your note in the March *Journal* on a "Pillar of Light" may be interestingly supplemented from our city, as I presume from any western city where atmospheric conditions are similar. Frequently, on clear, cold nights, every arc street-light has its "pillar of light." It is indeed a pretty sight, hundreds of these stately, brilliant pom-pons standing above our city, rank and file, miles in length.

A BRIGHT METEOR IN THE YUKON.

Further information would be very welcome regarding a great meteor seen in the Yukon on the evening of Tuesday, February 26, 1918. According to a press despatch, "at 8.45 o'clock a giant meteor shot northward across the heavens, making the country as light as day. There was an apparent explosion which threw a flood of light everywhere. The whole phenomenon was visible for twenty seconds. It is known by telegraphic reports received here to have been visible from Fairbanks, Alaska, to Carmacks, Yukon Territory, a distance of approximately six hundred miles."

NEBULA N.G.C. 1068 (M77) HOLDS THE RECORD.

Bulletin No. 80 of the Lowell Observatory contains very interesting information regarding the above nebula, which at present holds the record for highest radial, as well as rotational, velocity. Dr. Slipher finds for the former 1120 km. per sec. of recession, and for the latter 300 km. per sec. at 1′ from the nucleus. The radial velocities of this object, as determined at Mt. Wilson and Lick, are 765 and 910 km., respectively, but it is contended that the circumstances under which these measurements were made were not so good as at Flagstaff.

But there is another peculiar feature of this nebula. The spectrum is composite, containing some dark lines and the chief emission lines typical of the gaseous nebulae, and these emission lines are not images of the slit of the spectrograph, but are small discs. It is hard to assign the cause of this, but it may be related to increasing pressure towards the centre of the nebula.

Dr. Slipher thinks he has evidence that the inner part of the nebula is turning into the arms of the spiral, like a winding spring. This has also been deduced for the Great Andromeda Nebula and some other spirals, and investigations in dynamics lead us to expect that all spiral nebulae rotate in the same one direction relative to their arms.

C. A. C.

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